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Diangelo et al.

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(54) **DENTAL FRAMEWORK**

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A61C 11/00 (2006.01)

(52) **U.S. Cl.** **433/213; 433/214**

(58) **Field of Classification Search** **433/173, 433/213, 214**

See application file for complete search history.

6,261,098 B1	7/2001	Persson
6,287,119 B1	9/2001	van Nifterick et al.
6,322,364 B1	11/2001	Oshida et al.
6,382,975 B1	5/2002	Poirier
6,558,162 B1	5/2003	Porter et al.
6,788,986 B1	9/2004	Traber et al.
6,790,040 B2	9/2004	Amber et al.
6,814,575 B2	11/2004	Poirier
6,835,066 B2	12/2004	Iilyama et al.
6,905,336 B2	6/2005	Summers
6,925,198 B2	8/2005	Scharlack et al.
7,020,325 B2	3/2006	Park
7,333,874 B2	2/2008	Taub et al.
7,425,131 B2	9/2008	Amber et al.
2003/0020906 A1	1/2003	Li et al.
2003/0108845 A1	6/2003	Giovannone et al.
2003/0219148 A1	11/2003	Scharlack et al.
2004/0089962 A1	5/2004	Valery et al.
2004/0106087 A1	6/2004	Weigl et al.
2005/0019728 A1	1/2005	Rostagno et al.
2005/0037320 A1	2/2005	Poirier
2005/0089822 A1	4/2005	Geng
2005/0170311 A1	8/2005	Tardieu et al.
2005/0186540 A1	8/2005	Taub et al.
2006/0040236 A1	2/2006	Schmitt
2006/0072810 A1	4/2006	Scharlack et al.
2006/0093988 A1	5/2006	Swaelens et al.
2006/0105294 A1	5/2006	Burger et al.
2006/0106484 A1	5/2006	Saliger et al.
2006/0115793 A1	6/2006	Kopelman et al.
2006/0122719 A1	6/2006	Kopelman et al.
2007/0134625 A1	6/2007	Leu et al.
2008/0131841 A1	6/2008	Taub et al.
2008/0176188 A1	7/2008	Holzner et al.

* cited by examiner

(56) **References Cited**

U.S. PATENT DOCUMENTS

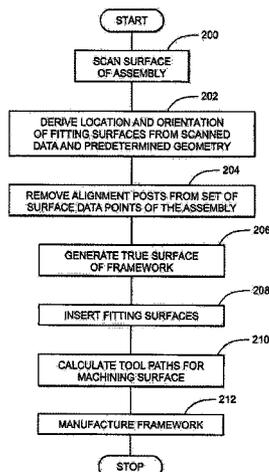
4,663,720 A	5/1987	Duret et al.
4,742,464 A	5/1988	Duret et al.
5,401,170 A	3/1995	Nonomura
5,562,448 A	10/1996	Mushabac
5,630,717 A	5/1997	Zuest et al.
5,725,376 A	3/1998	Poirier
5,851,115 A	12/1998	Carlsson et al.
5,857,853 A	1/1999	van Nifterick et al.
5,885,078 A	3/1999	Cagna et al.
5,938,446 A	8/1999	Andersson et al.
5,993,214 A	11/1999	Persson
6,142,782 A *	11/2000	Lazarof 433/174

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(57) **ABSTRACT**

A method of preparing a dental framework or mathematical model thereof by creating a replica of a patient's mouth or a framework to be inserted into the patient's mouth, electronically scanning the replica or framework, electronically determining a surface model of a dental framework and manufacturing the framework.

10 Claims, 18 Drawing Sheets



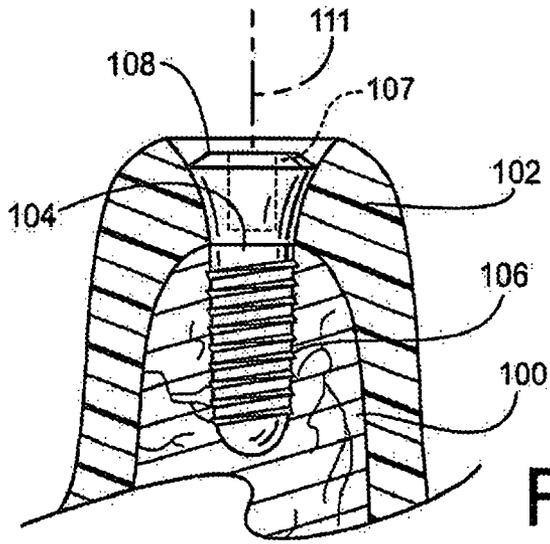


FIG. 1

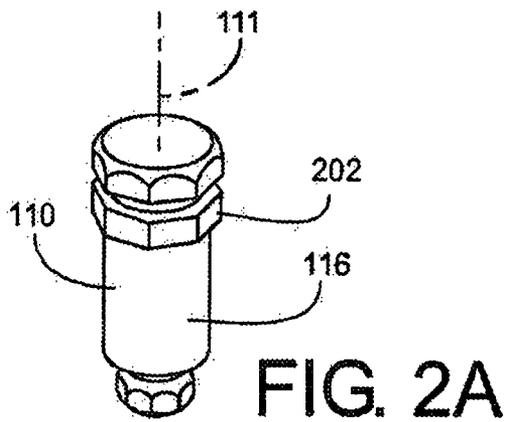


FIG. 2A

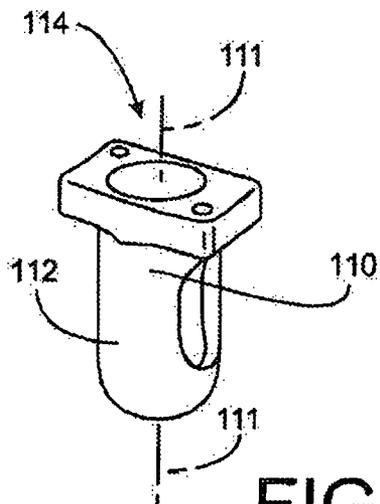


FIG. 2B

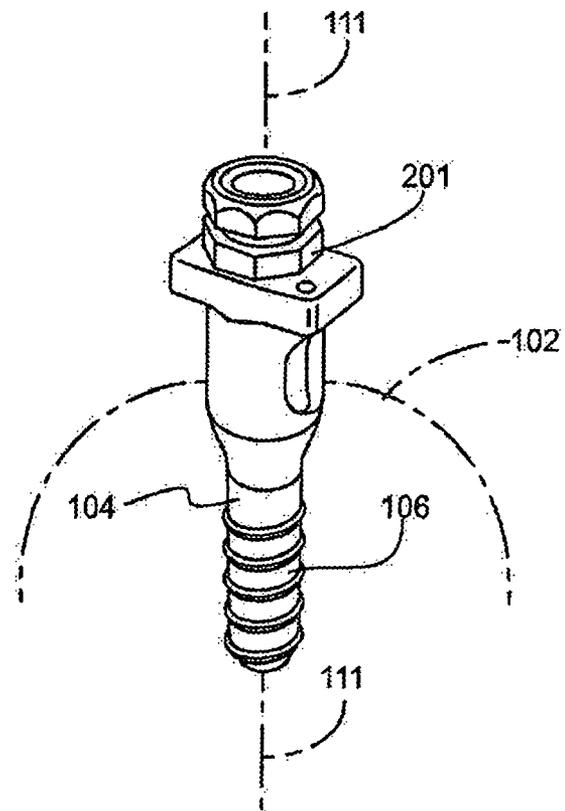


FIG. 3

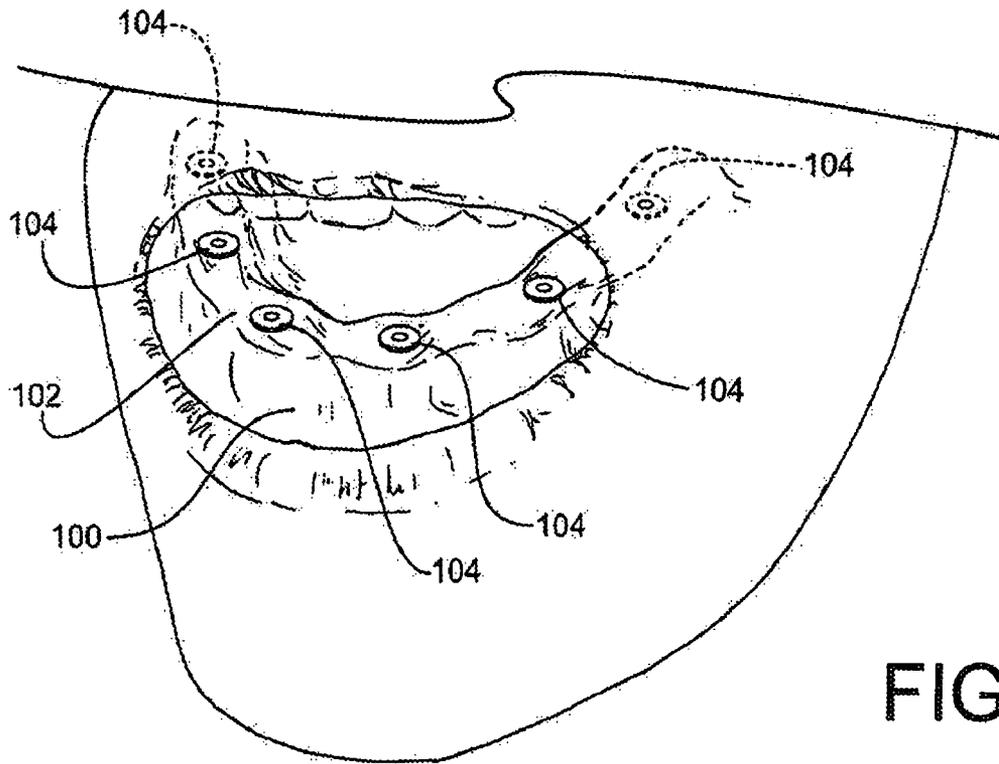


FIG. 4

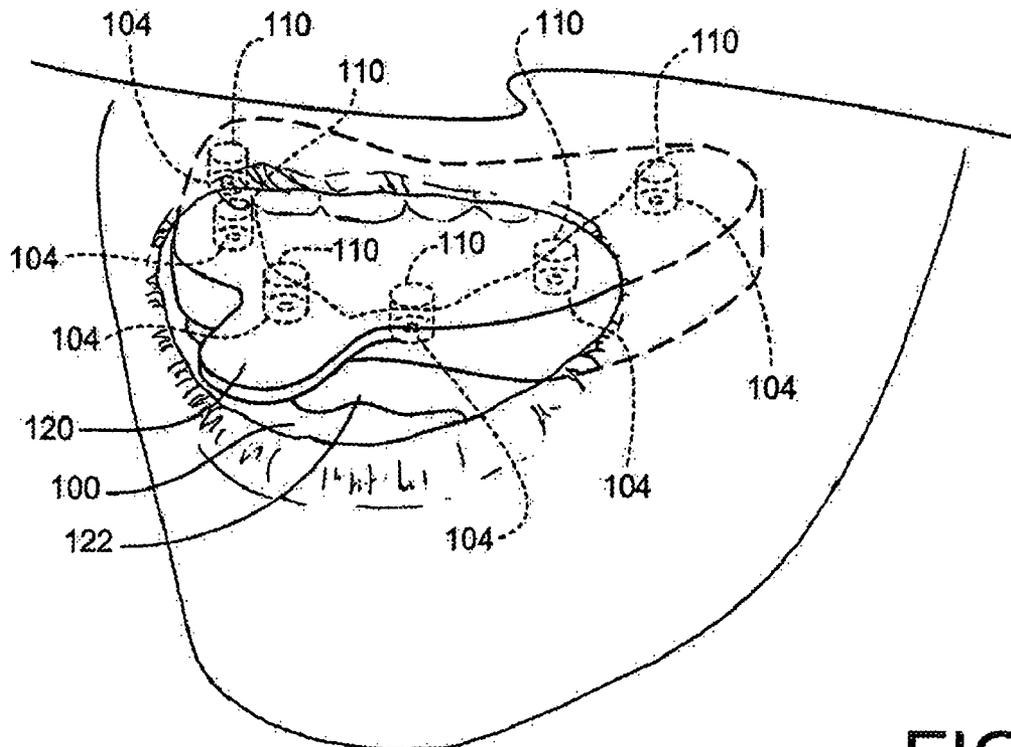
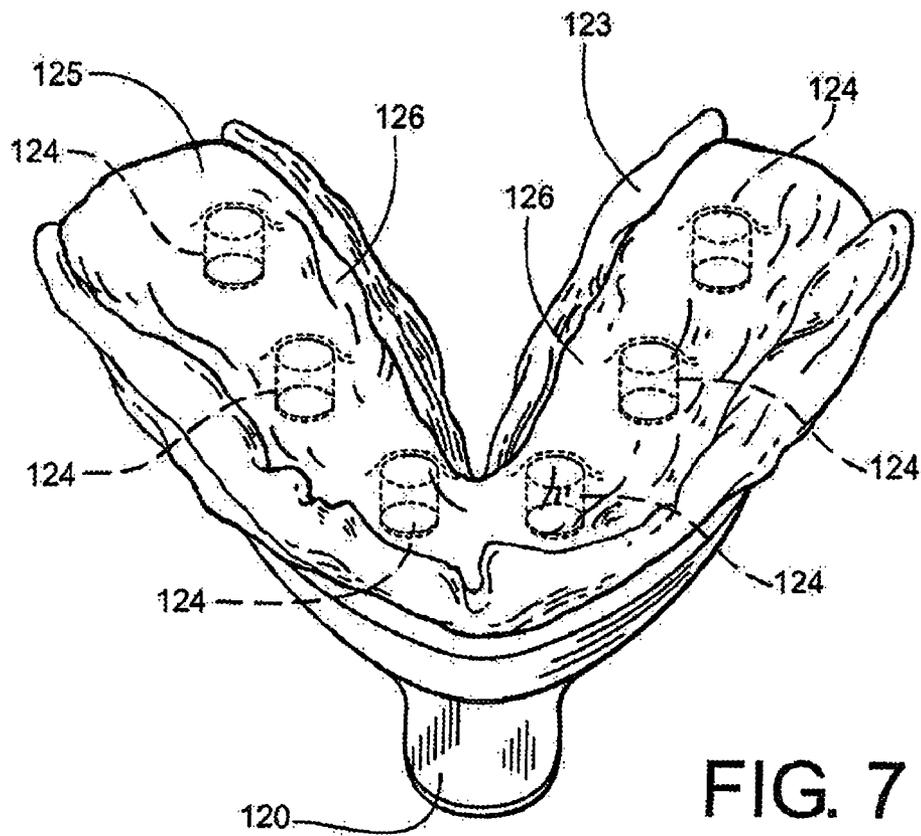
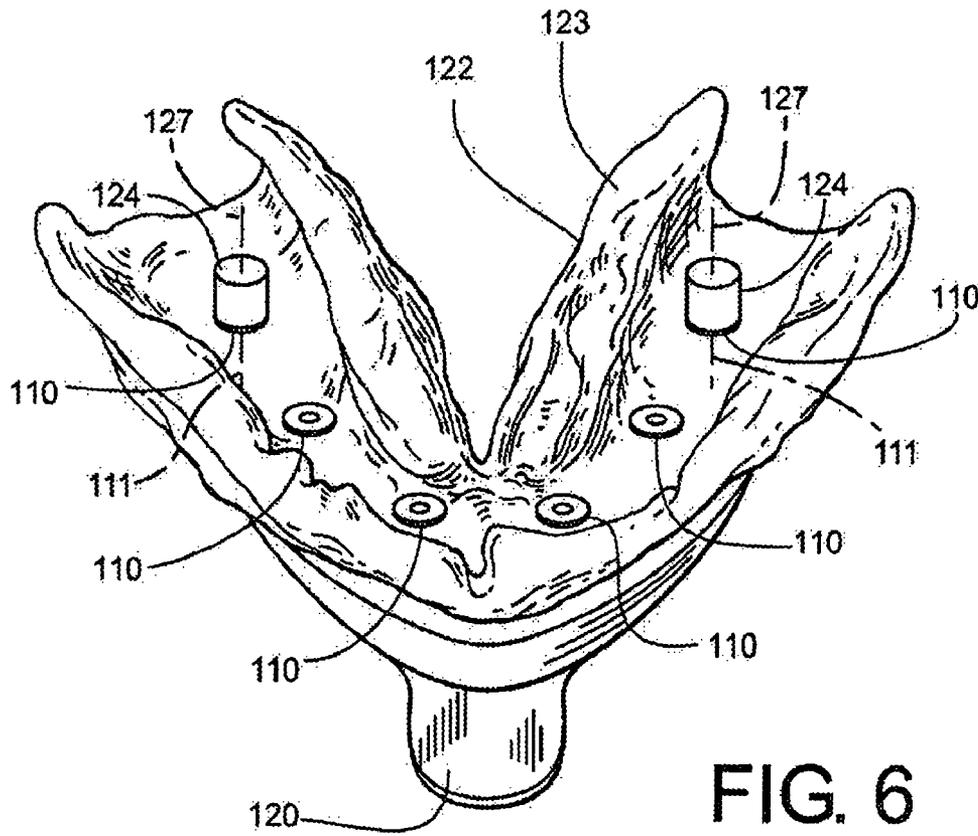


FIG. 5



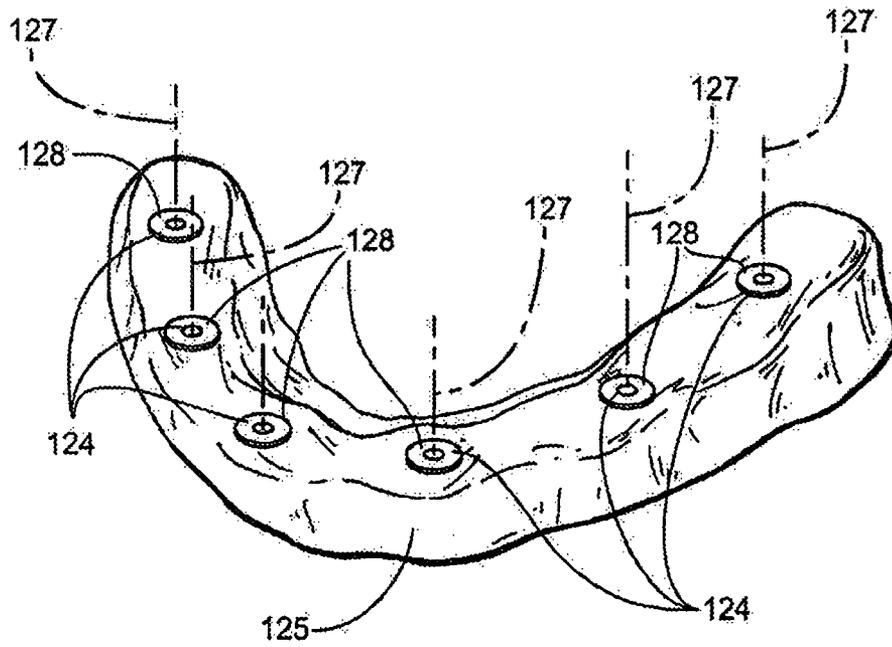


FIG. 8

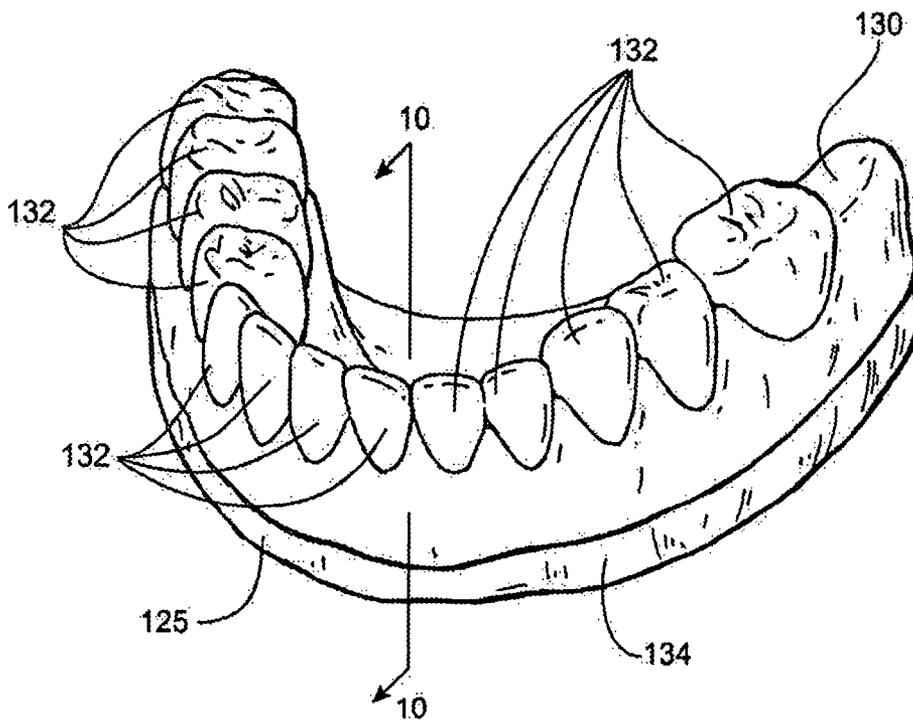


FIG. 9

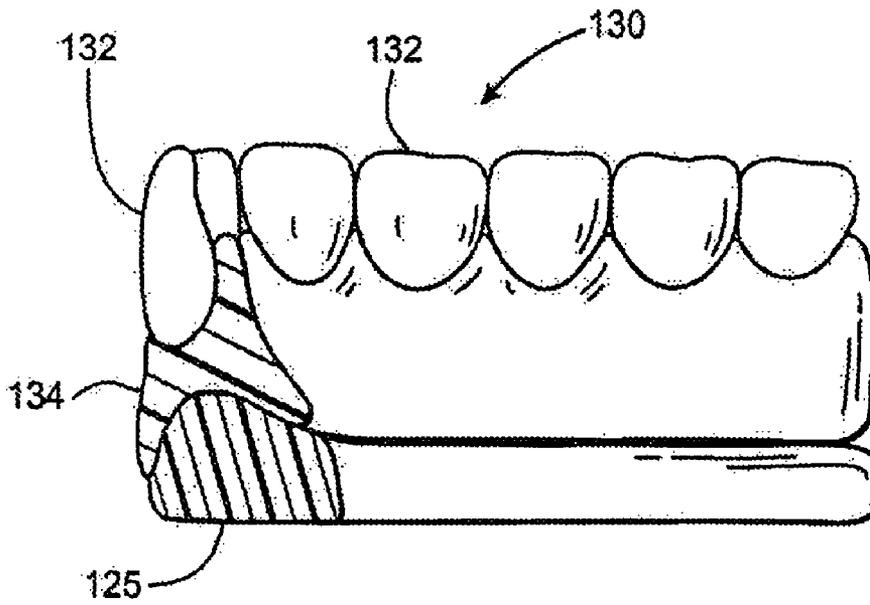


FIG. 10

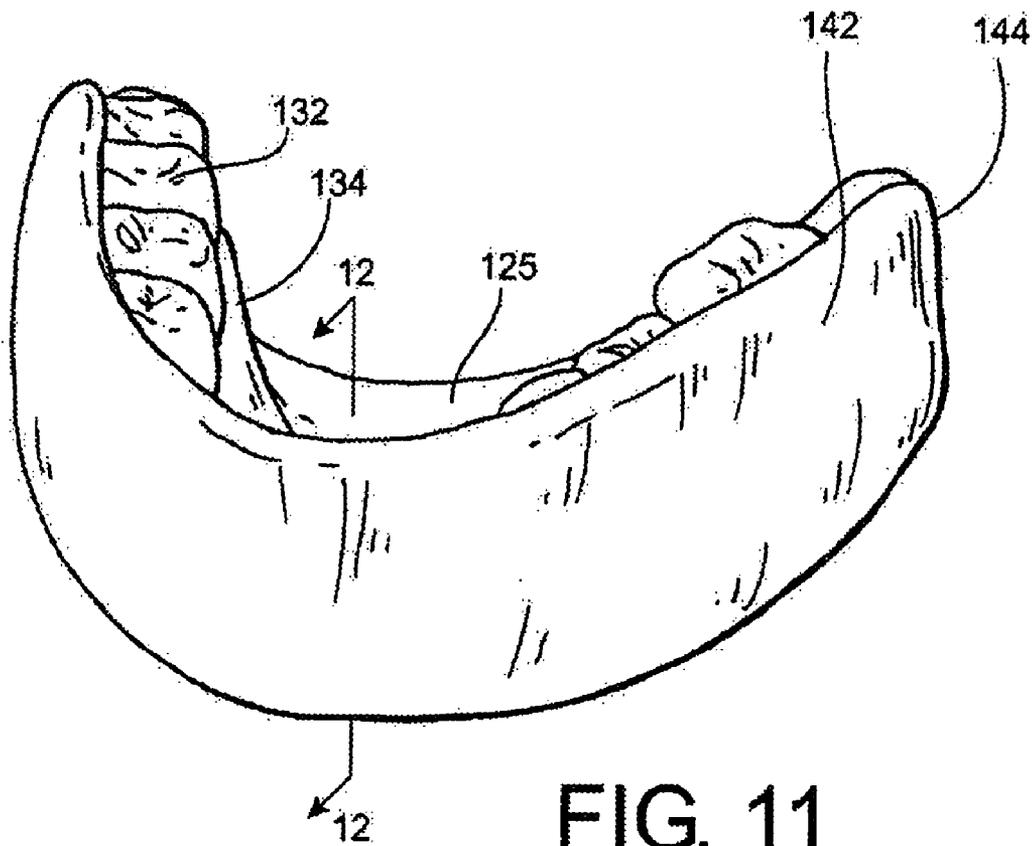


FIG. 11

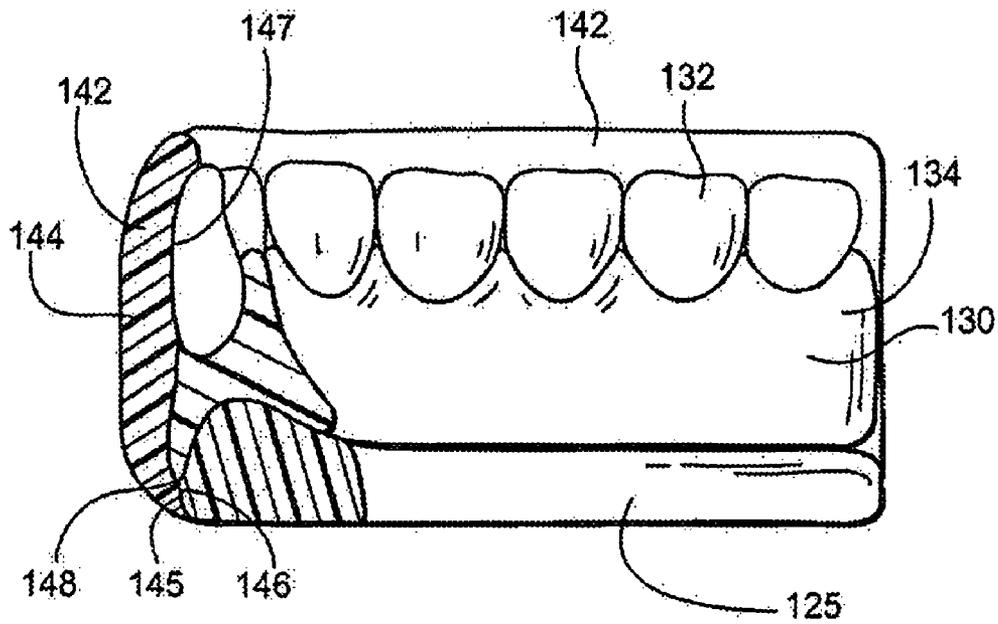


FIG. 12

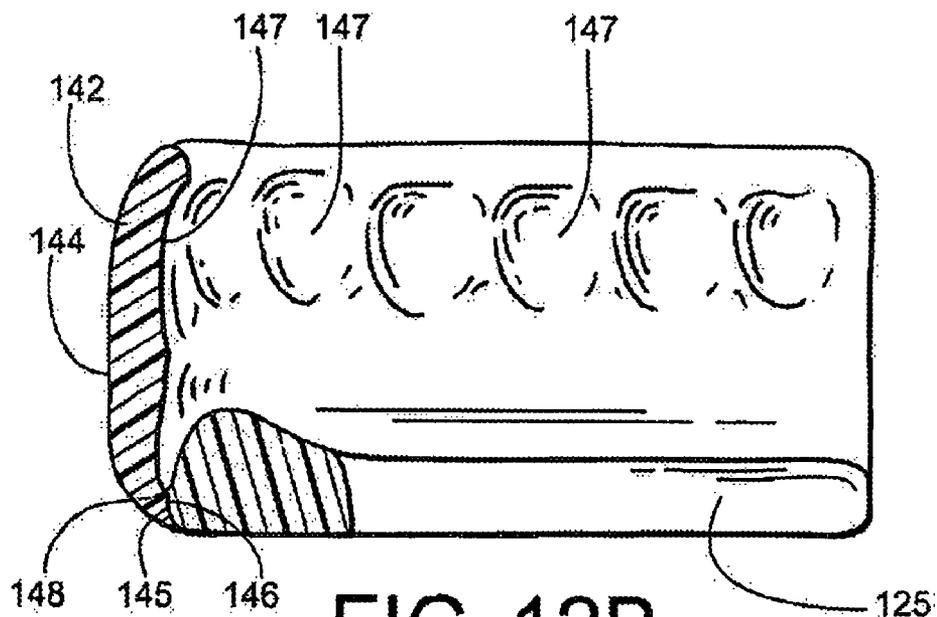


FIG. 12B

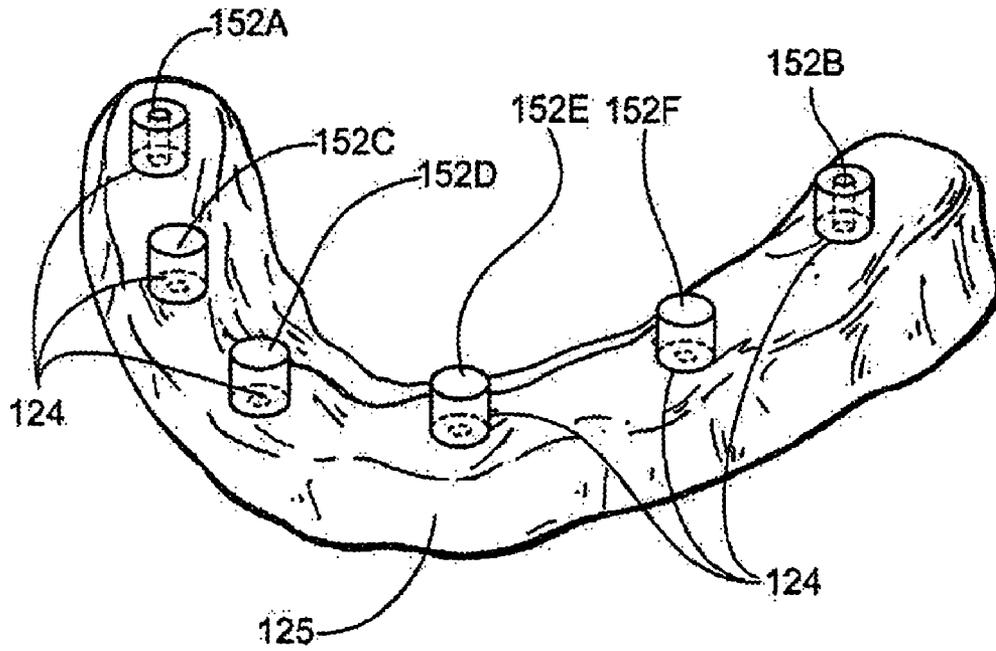


FIG. 13A

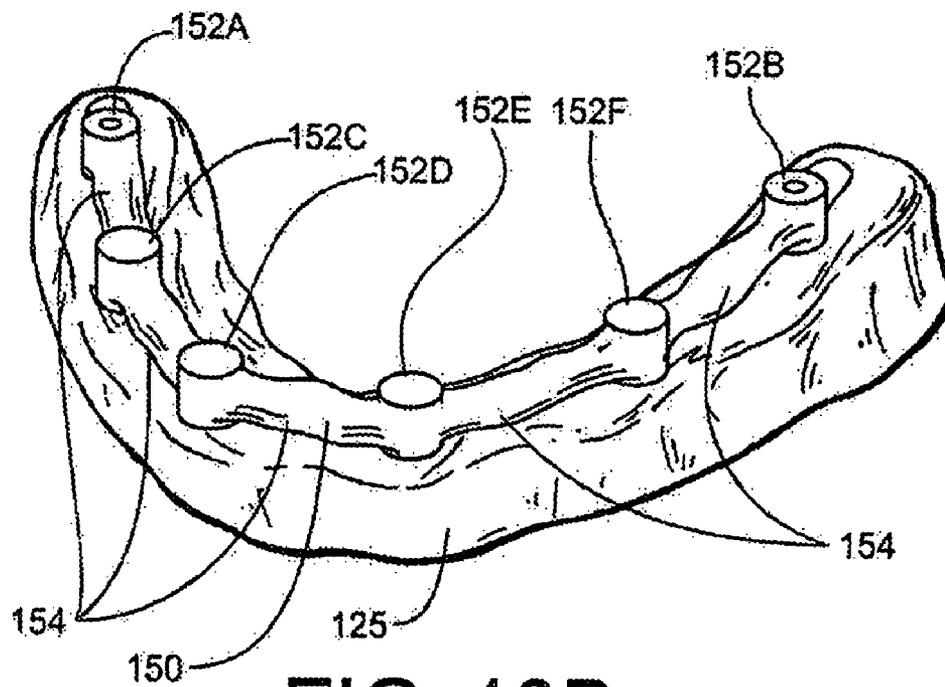


FIG. 13B

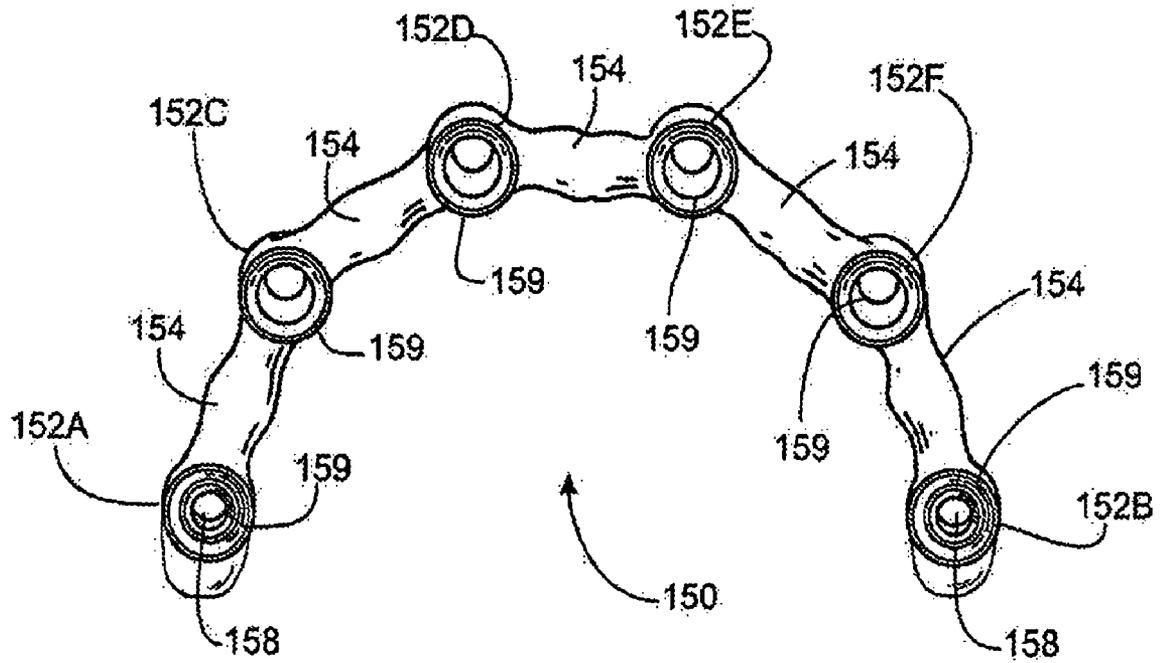


FIG. 13C

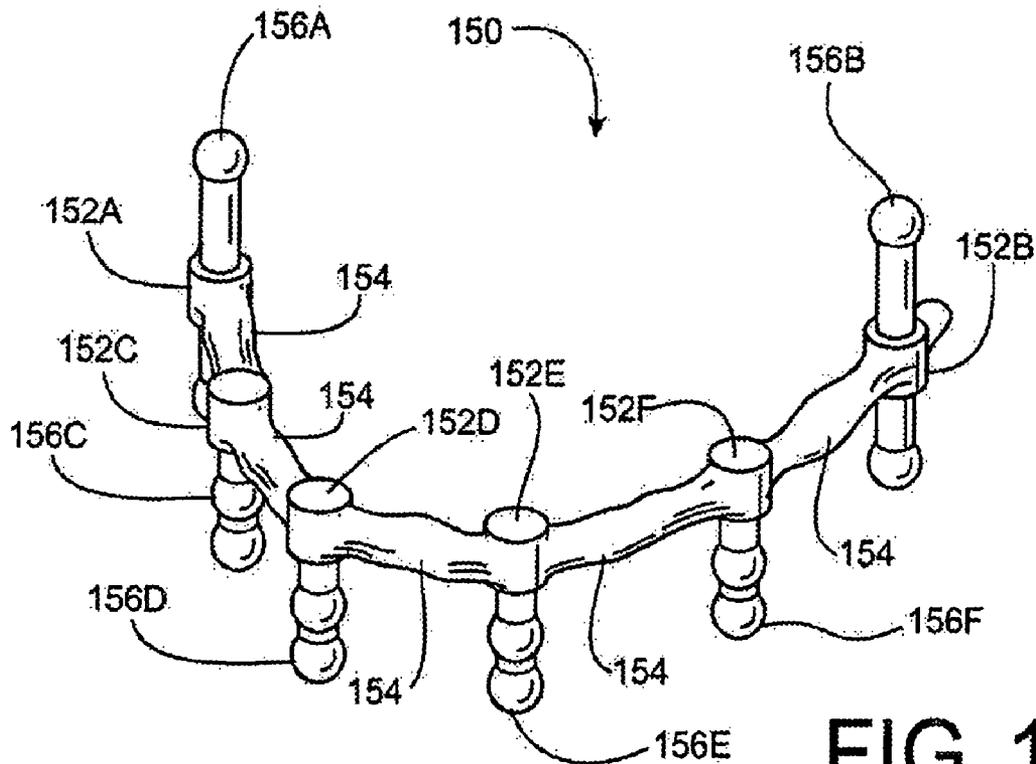


FIG. 14

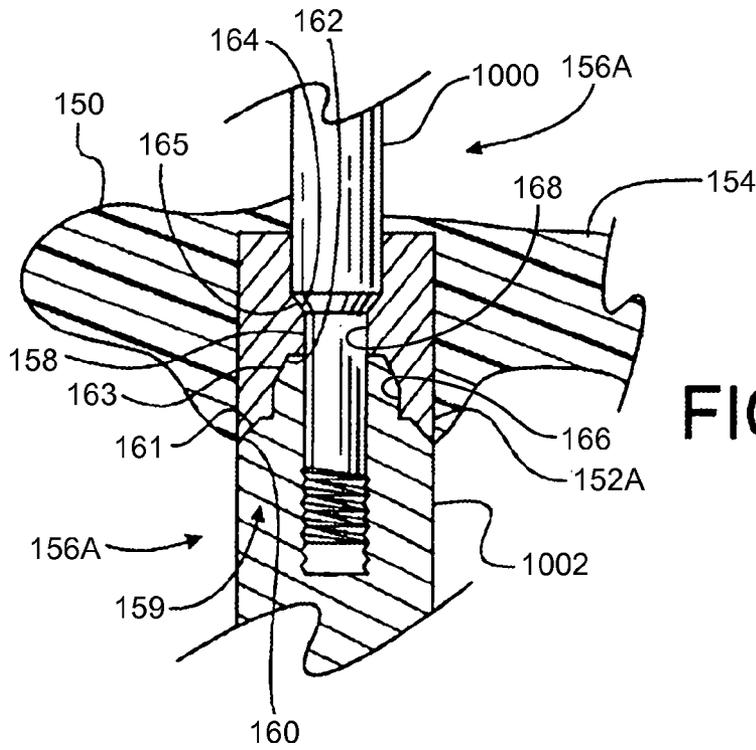


FIG. 15

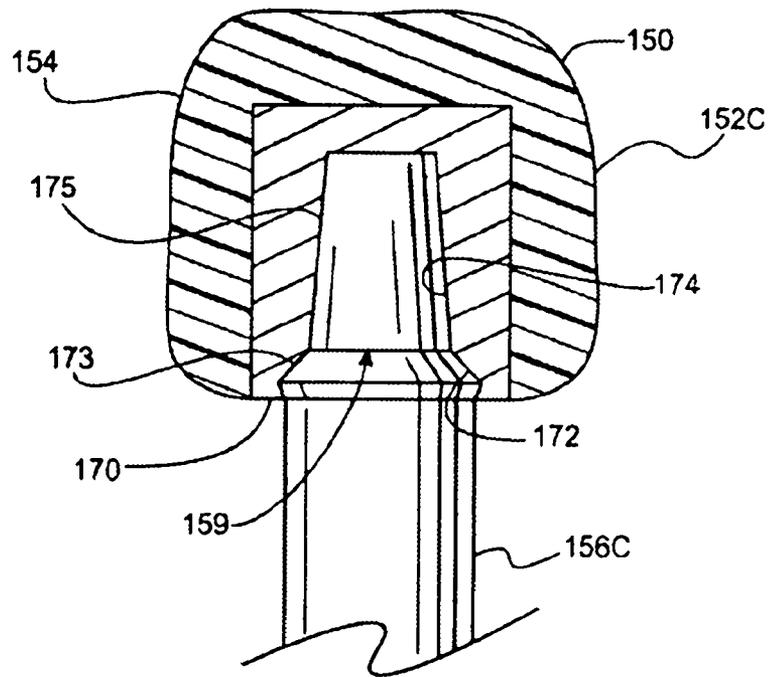


FIG. 16

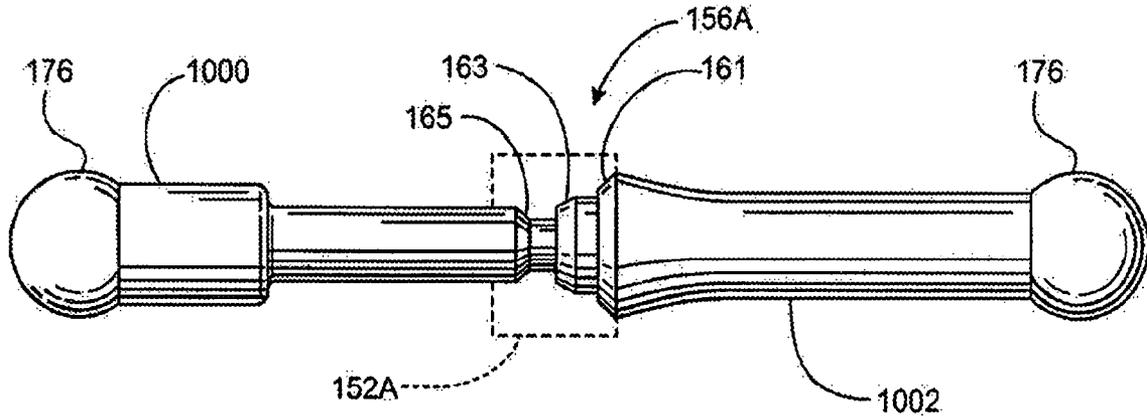


FIG. 17

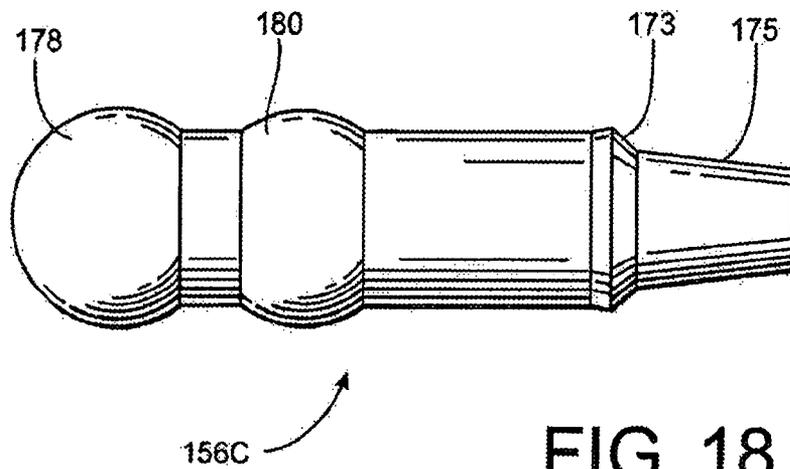


FIG. 18

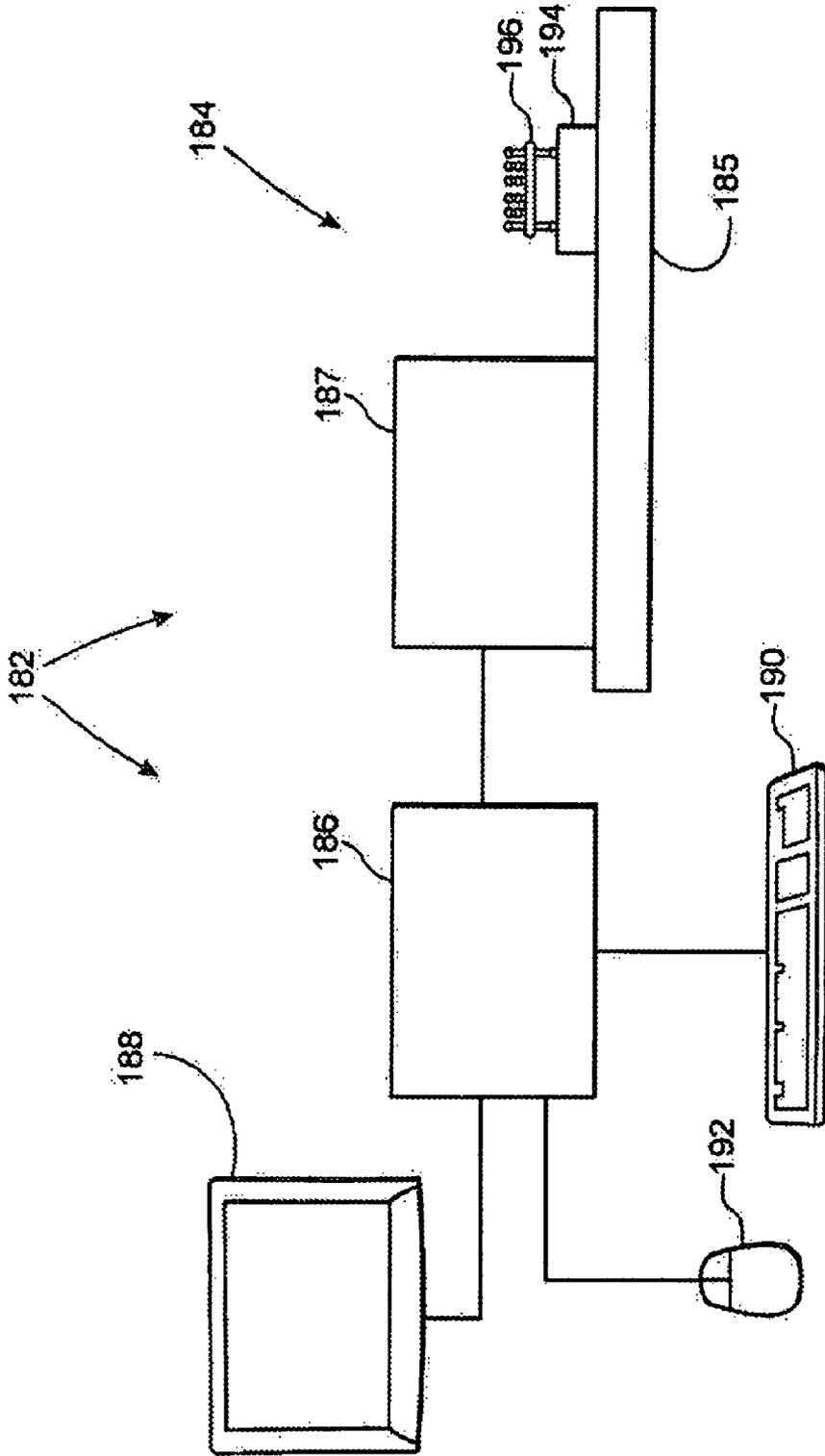


FIG. 19

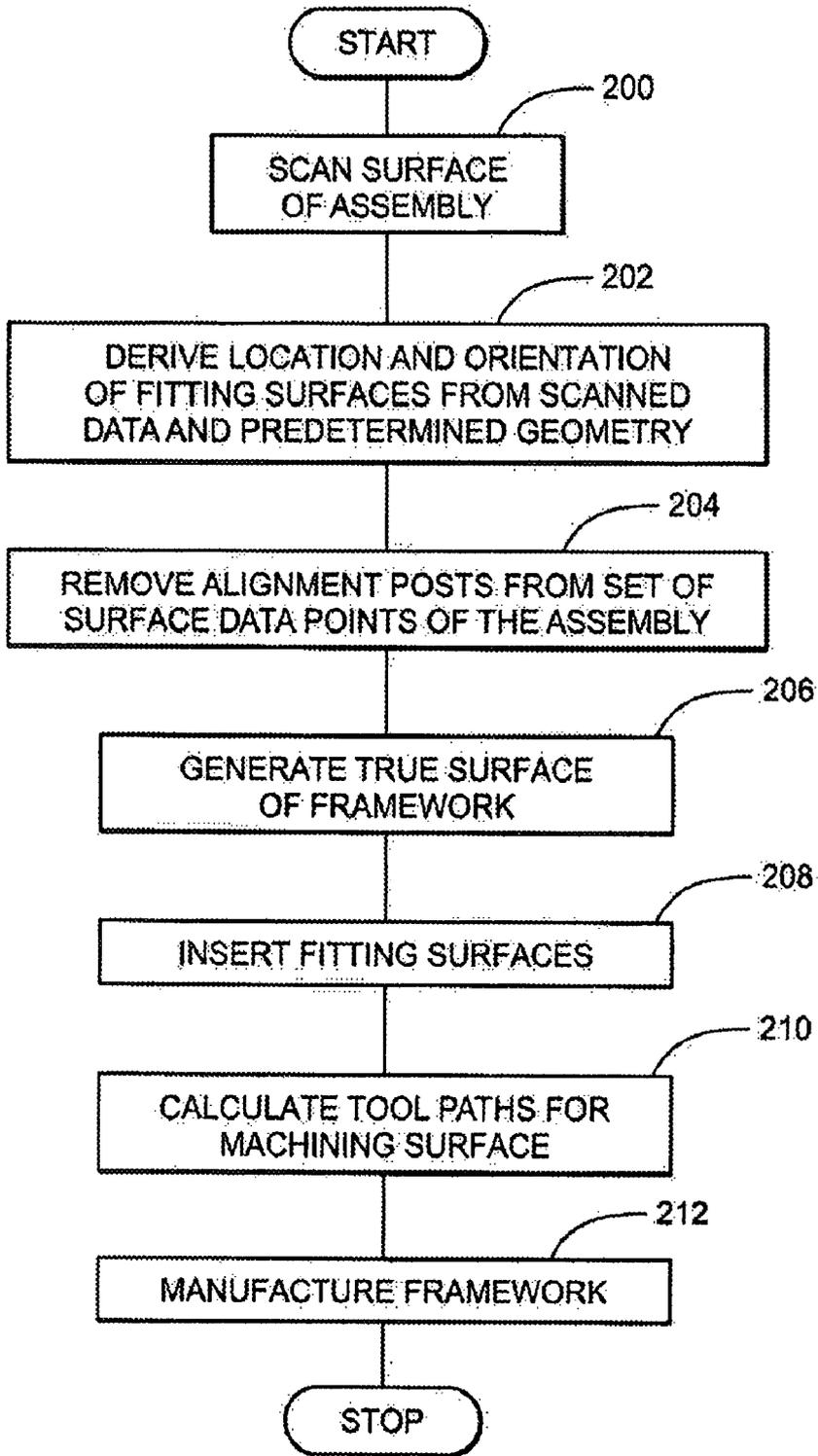


FIG. 20

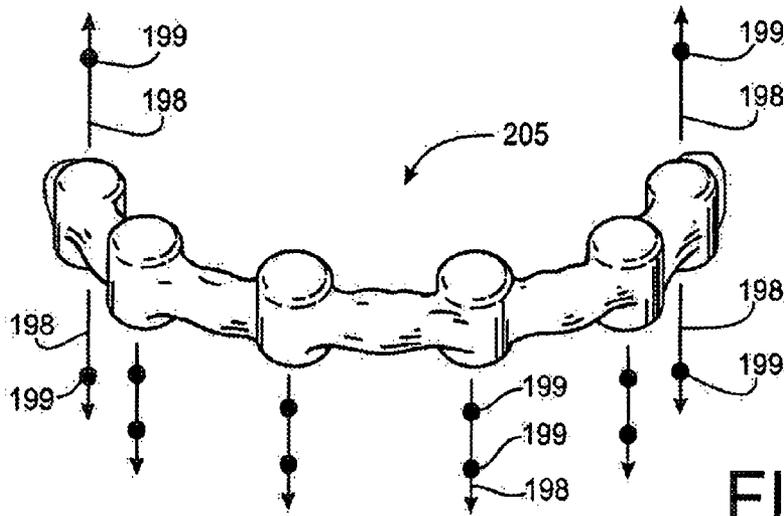


FIG. 21

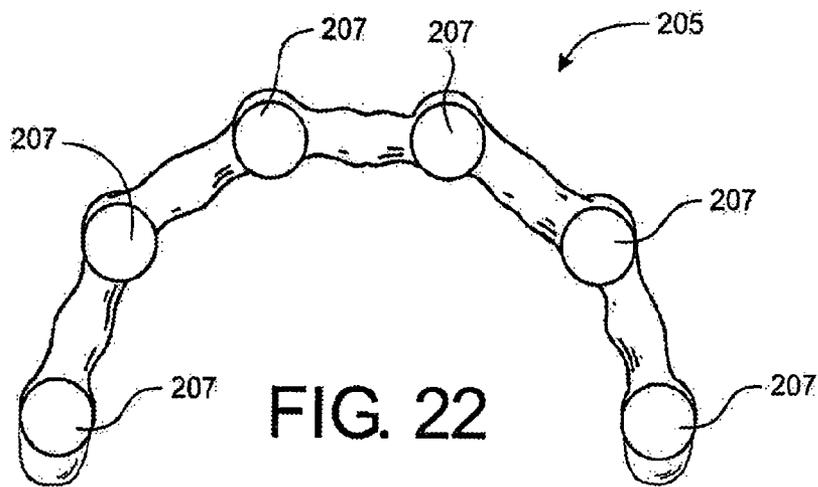


FIG. 22

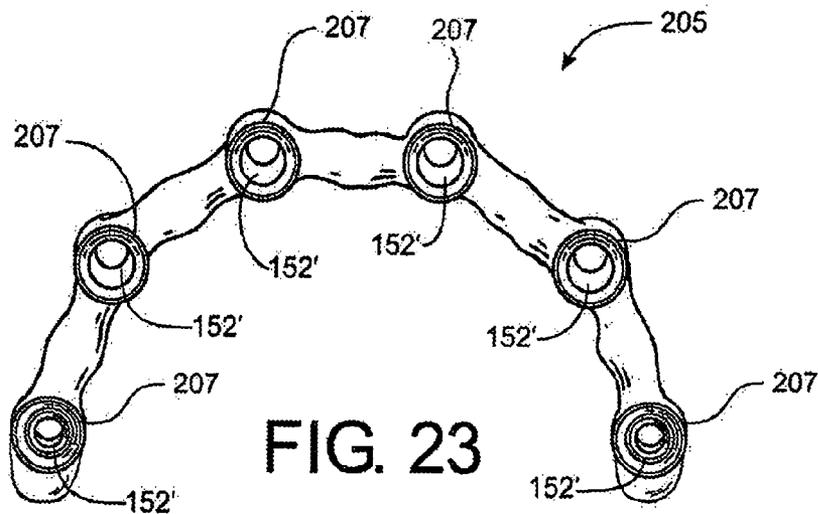


FIG. 23

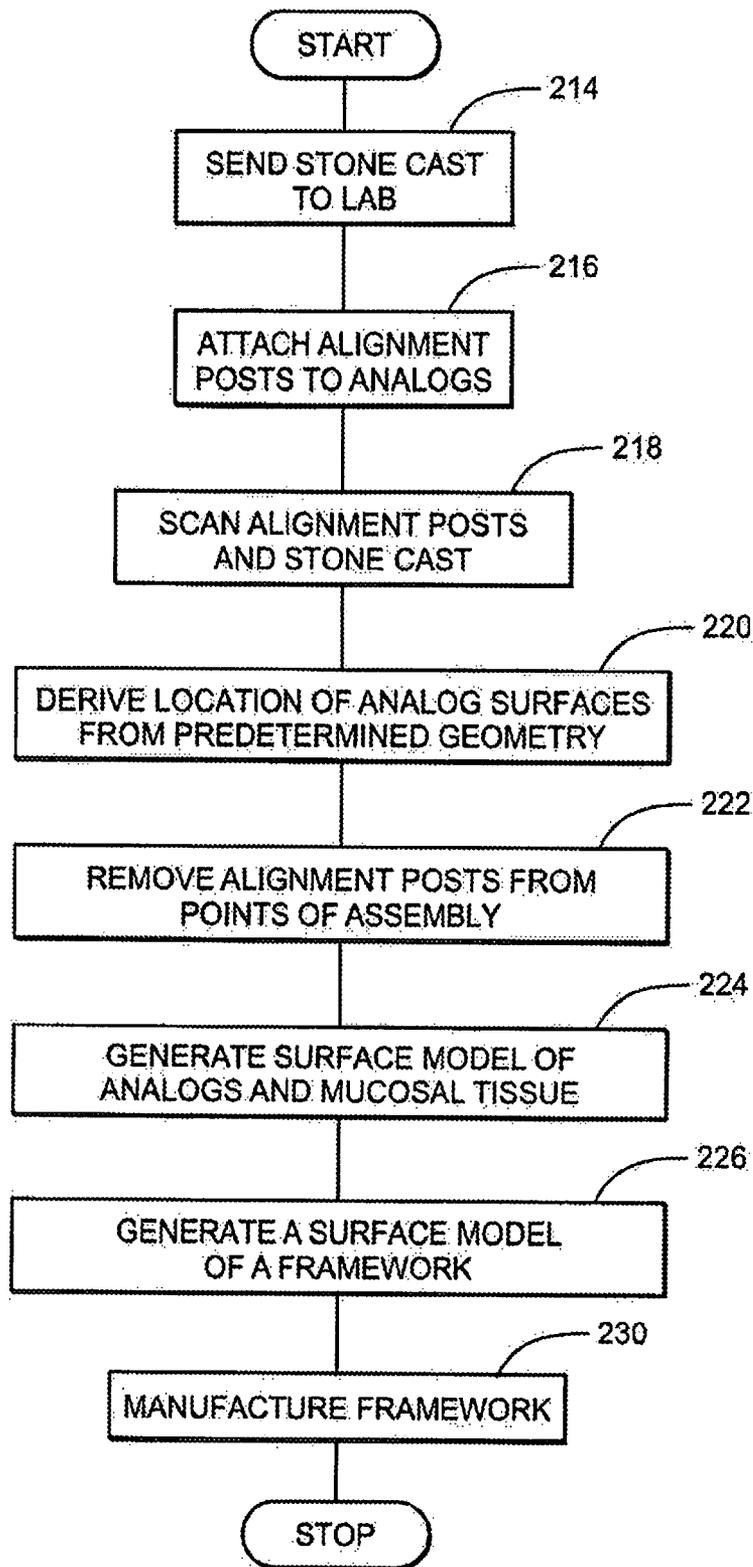
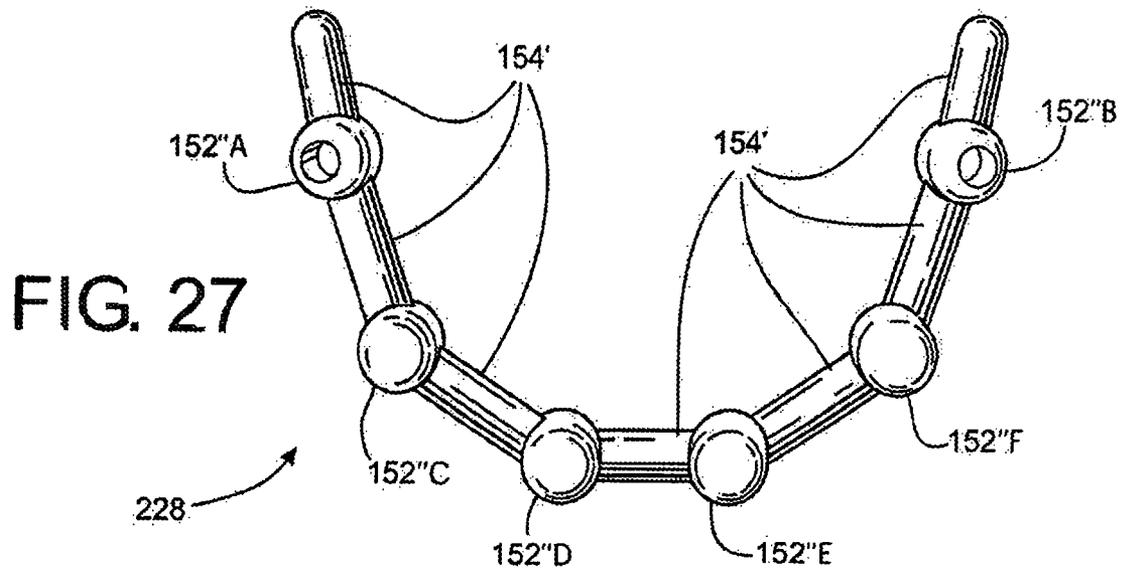
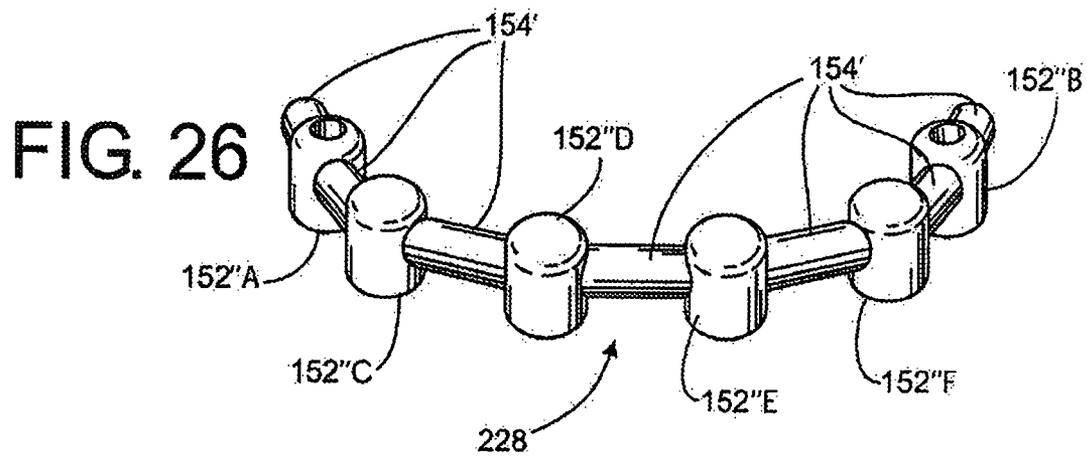
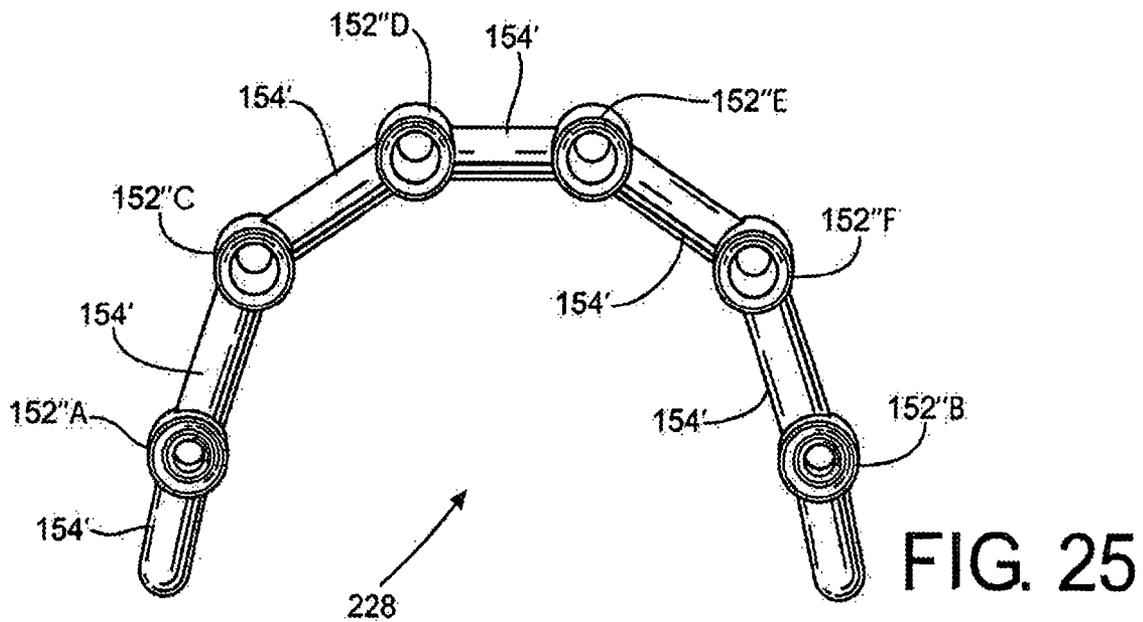


FIG. 24



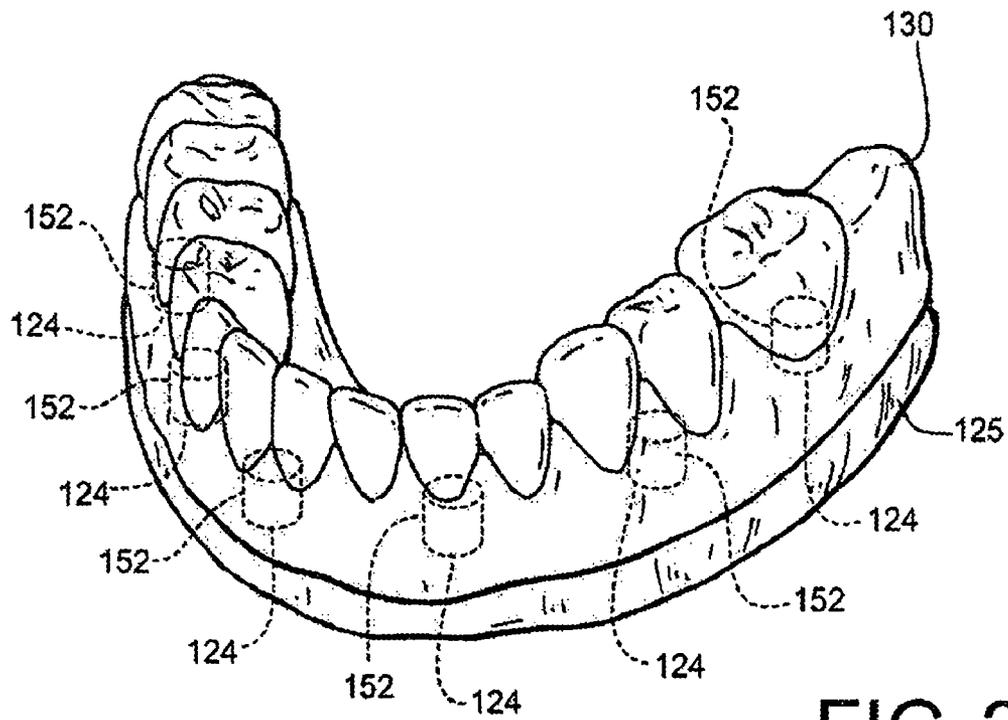


FIG. 28

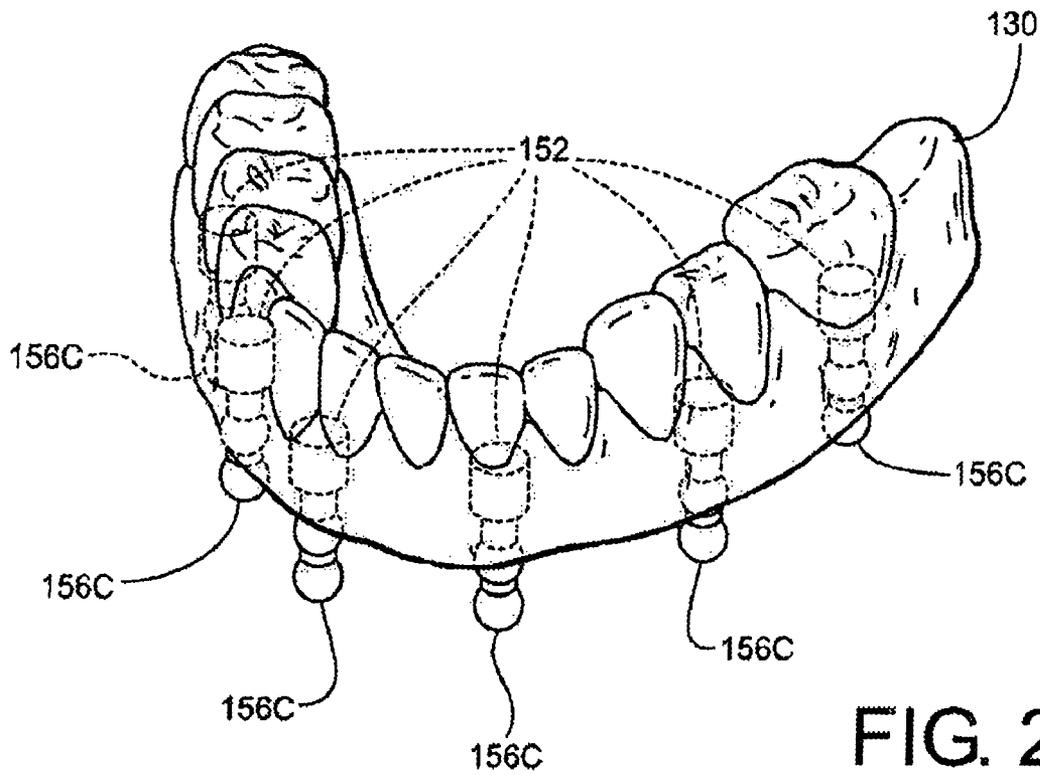
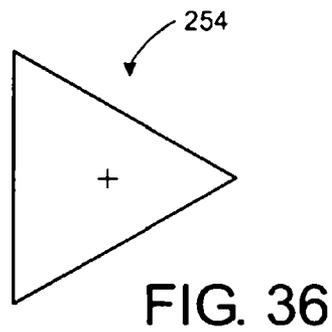
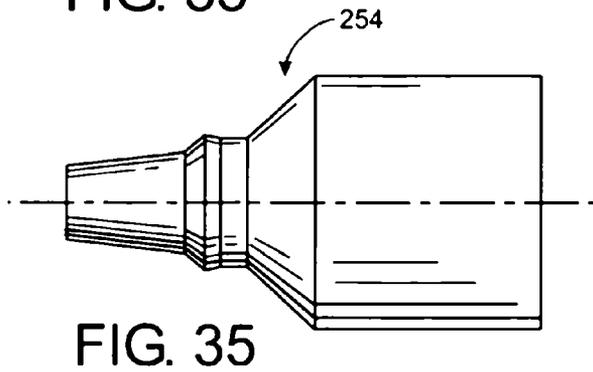
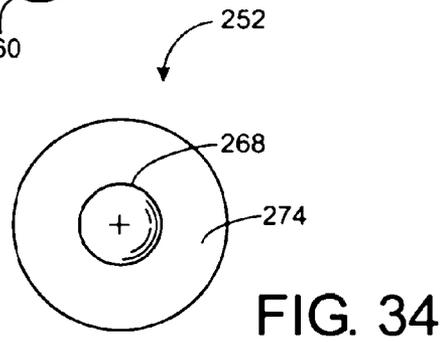
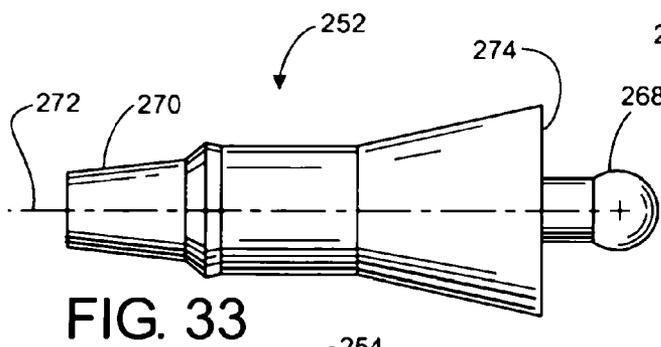
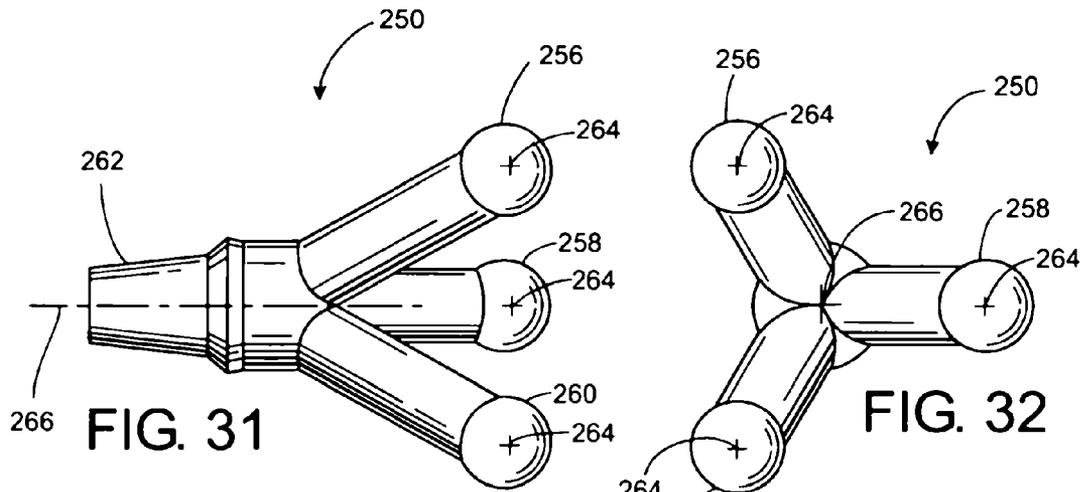


FIG. 29



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DENTAL FRAMEWORK

FIELD OF THE INVENTION

The invention relates generally to the creation of dental frameworks, and typically dental frameworks for dentures. More particularly it relates to computer implemented methods of manufacturing dental frameworks.

BACKGROUND OF THE INVENTION

Many different processes have been devised to make a dental framework. In the most common of these a dentist makes an impression of a patient's mouth in which copings are embedded that are attached to anchors in the patient's mouth to which the dental framework of the denture will be later attached.

The dentist then attaches analogs to the copings and casts a stone cast replica of the patient's mouth.

The dentist then forms a replica or model dental framework on top of the stone cast in the exact size and shape he wishes the actual dental framework. The dentist then lost wax casts the actual dental framework from the model dental framework.

Unfortunately these models are warped and distorted by the casting process and must be cut apart and soldered together until they fit properly.

What is needed is a method of manufacturing a dental framework that is more precise than these cast frameworks. It is an object of at least one aspect of this invention to provide such a dental framework. It is also an object of at least one aspect of this invention to provide a method for registering dental surfaces that have been digitally scanned in order to define a volume or space in which a computer-generated framework can be disposed.

These and other objects of the invention will become clear upon examination of the various embodiments and methods described below.

SUMMARY OF THE INVENTION

In accordance with a first aspect of the invention, a method of preparing a dental framework for a dental prosthesis for a patient is provided, the patient having a plurality of anchors embedded in the patient's mandible or maxilla, comprising the steps of coupling a plurality of fittings to a plurality of analogs in a positive replica of a patient's mandible or maxilla; fixing the fittings together with a bridging structure to form a model dental framework; fixing a surface extension to each of the fittings; sequentially scanning a plurality of points on the surface of the model dental framework and the surface extensions to create a point cloud dataset; for each of the fittings represented in the point cloud dataset, deriving from the points scanned from the surface extension coupled to that fitting a desired location and orientation of a corresponding mount to engage the analog on which that fitting was mounted; generating a surface model of an actual dental framework from the derived desired locations and orientations of the mounts; and manufacturing the actual dental framework from the surface model.

The mounts may be configured to be fixed directly to anchors in a patient's mouth. The mounts may be configured to be fixed to intermediate structures that are in turn fixed to the anchors. Each of the surface extensions may have a longitudinal axis that is coaxial with a corresponding longitudinal axis of the fitting on which it is fixed.

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In accordance with a second aspect of the invention, a method of preparing an actual dental framework for a dental prosthesis for a patient from a model framework is provided, wherein the model framework comprises a plurality of fittings configured to engage a plurality of corresponding anchors in the patient's mouth, and a bridging structure coupling the fittings together, the method comprising the steps of fixing surface extensions to each of the plurality of fittings; sequentially scanning a plurality of points on the surface of the model dental framework and the surface extensions to generate a point cloud dataset; for each of the fittings, deriving from the points scanned from the surface extension coupled to that fitting a desired location and orientation of a corresponding mount to engage the analog on which that fitting was mounted; and generating a surface model of an actual dental framework from the derived desired locations and orientations of the corresponding mounts.

The mounts may be configured to be fixed directly to anchors in a patient's mouth. The mounts may be configured to be fixed to intermediate structures that are in turn fixed to the anchors. Each of the surface extensions has a longitudinal axis that is coaxial with a corresponding longitudinal axis of the fitting on which it is fixed.

In accordance with a third aspect of the invention, a method of preparing a dental prosthesis for a patient is provided, comprising the steps of coupling a plurality of copings to a plurality of anchors or surmounted abutments embedded in a patient's mandible or maxilla; impressing a negative replica of the patient's mandible or maxilla; removing the negative replica and embedded copings; fixing surface extensions to each of the copings; scanning a plurality of points on the surface extensions; deriving from the plurality of points a desired location and orientation of mounts to engage the anchors or surmounted abutments on which the copings were mounted; generating a surface model of the dental prosthesis from the derived desired locations and orientations of the mounts; and manufacturing the dental prosthesis from the surface model.

The step of generating a surface model may include the step of generating a surface model of at least a portion of the mounts. The surface model of the at least a portion of the mounts may include a surface model of surfaces configured to engage the plurality of anchors or surmounted abutments. The step of generating a surface model may include the step of generating a surface model of a bridging structure that extends between and couples the mounts. The dental prosthesis may comprise a dental framework and further wherein the dental framework may comprise the mounts. The method of claim 9, wherein the dental prosthesis is a denture.

In accordance with a fourth aspect of the invention, a method of preparing a dental prosthesis for a patient from a negative replica of the patient's maxilla or mandible is provided, the negative replica including a plurality of copings configured to engage a corresponding plurality of anchors or surmounted abutments in the patient's maxilla or mandible, the method comprising the steps of fixing surface extensions to each of the copings; scanning a plurality of points on the surface extensions; deriving from the plurality of points a desired location and orientation of mounts configured to engage the anchors or surmounted abutments; and generating a surface model of the dental prosthesis from the derived desired locations and orientations of the mounts.

The step of generating a surface model may include the step of generating a surface model of at least a portion of the mounts. The surface model of the at least a portion of the mounts may include a surface model of surfaces configured to engage the plurality of anchors or surmounted abutments.

The step of generating a surface model may include the step of generating a surface model of a bridging structure that extends between and couples the mounts. The dental prosthesis may comprise a dental framework and the dental framework may comprise the mounts. The dental prosthesis may be a denture.

In accordance with a fifth aspect of the invention, a method of preparing a dental prosthesis for a patient from a negative replica of the patient's maxilla or mandible is provided, the negative replica including a plurality of copings configured to engage a corresponding plurality of anchors or surmounted abutments in the patient's maxilla or mandible, the method comprising the steps of scanning a surface of the negative replica to provide a first point cloud dataset representing a surface of the negative replica; and generating a surface model of the dental prosthesis from the first point cloud dataset.

The surface of the negative replica may include surfaces of copings. The method may further include the steps of fixing surface extensions to the negative replica and scanning the surface extensions to provide a second point cloud dataset. The dental prosthesis may comprise a dental framework and the dental framework may comprise the mounts. The dental prosthesis may comprise a denture.

In accordance to a sixth aspect of the invention, a method of computer generating a digital model of a dental prosthesis for a patient is provided, the method comprising the steps of coupling a plurality of surface extensions to analogs or surmounted abutments embedded in a positive replica of the patient's mouth, the positive replica of the patient's mouth including a positive replica of the patient's mucosal tissues; sequentially scanning surfaces of the surface extensions and deriving therefrom a location of the analogs or surmounted abutments; sequentially scanning the replica of the patient's mucosal tissues to create a point cloud dataset indicating a surface of the patient's mucosal tissues with respect to the anchors or surmounted abutments; and computer-generating a digital model of a dental prosthesis, the digital model comprising model mounts configured to engage analogs or surmounted abutments in the patient's mandible or maxilla, the digital model also comprising model bridging structures extending between and coupling the model mounts, wherein the model bridging structures are computer-generated such that they do not intersect the surface of the patient's mucosal tissue as indicated by the point cloud dataset.

The bridging structure may comprise a dental framework. The bridging structure may comprise a component of a denture. The model bridging structure may comprise computer-generated to be spaced a predetermined distance away from the surface of the patient's mucosal tissue as indicated by the point cloud dataset.

In accordance with a seventh aspect of the invention, a method of creating a digital model of a dental prosthesis of a patient is provided, the method comprising making an impression of the patient's mouth; making a stone cast of the impression; forming a diagnostic wax-up on the stone cast; digitally scanning at least a first surface of the diagnostic wax-up to form a first point cloud dataset; digitally scanning at least a second surface of the impression to form a second point cloud dataset; and digitally registering the first and second point cloud datasets.

The step of digitally registering may comprise the steps of registering a portion of the first point cloud dataset with a portion of the second point cloud dataset; wherein the surface of the diagnostic wax-up, from which the portion of the first point cloud dataset was scanned, was formed by a portion of a common surface of the stone cast; and further wherein the

portion of the second point cloud dataset was formed by a portion of a surface of the impression that formed the common surface of the stone cast. The step of digitally scanning at least a first surface of the diagnostic wax-up may comprise the step of digitally scanning both a first surface of the diagnostic wax-up and a first portion of the surface of the stone cast while said diagnostic wax-up is mounted on the stone cast to create the first point cloud dataset, which comprises at least a common point cloud dataset including points defined by the diagnostic wax-up and points defined by the surface of the stone cast. The step of digitally registering the first and second point cloud datasets may comprise the step of digitally registering the points defined by the surface of the stone cast in the common point cloud dataset, and points defined by the impression in the second point cloud dataset. A first impression surface may be formed the points defined by the impression in the second point cloud dataset, and the first impression surface may form the stone cast surface from which the points defined by the surface of the stone cast in the common point cloud dataset were scanned.

In accordance with an eighth aspect of the invention, a method of creating a digital model of a dental prosthesis of a patient from an impression taken of the patient's mouth, a stone cast made from the impression, and a diagnostic wax-up made on the stone cast is provided, the method comprising the steps of digitally scanning at least a first surface of the diagnostic wax-up to form a first point cloud dataset; digitally scanning at least a second surface of the impression to form a second point cloud dataset; and digitally registering the first and second point cloud datasets.

The step of digitally registering may comprise the steps of registering a portion of the first point cloud dataset with a portion of the second point cloud dataset; wherein the surface of the diagnostic wax-up from which the portion of the first point cloud dataset was scanned was formed by a portion of a surface of the stone cast that was formed by a common surface of the stone cast; and further wherein the portion of the second point cloud dataset was formed by a portion of a surface of the impression that formed the common surface of the stone cast. The step of digitally scanning at least a first surface of the diagnostic wax-up may comprise the step of digitally scanning both a first surface of the diagnostic wax-up and a first portion of the surface of the stone cast while said diagnostic wax-up is mounted on the stone cast to create the first point cloud dataset, which comprises at least a common point cloud dataset including points defined by the diagnostic wax-up and points defined by the surface of the stone cast. The step of digitally registering the first and second point cloud datasets may comprise the step of digitally registering the points defined by the surface of the stone cast in the common point cloud dataset, and points defined by the impression in the second point cloud dataset. A first impression surface may form the points defined by the impression in the second point cloud dataset, and further wherein said first impression surface may form the stone cast surface from which the points defined by the surface of the stone cast in the common point cloud dataset were scanned.

In accordance with a ninth aspect of the invention, a method of creating a digital model of a dental prosthesis of a patient is provided, comprising the steps of making an impression of the patient's mouth; making a stone cast of the impression; making a diagnostic wax-up on the stone cast; digitally scanning at least a first surface of the diagnostic wax-up to form a first point cloud dataset; digitally scanning at least a second surface of the stone cast to form a second point cloud dataset; and digitally registering the first and second point cloud datasets.

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The step of digitally registering may comprise the steps of digitally registering a portion of the first point cloud dataset with a portion of the second point cloud dataset; wherein the portion of the first point cloud dataset was scanned from a portion of the diagnostic wax-up formed by a forming surface of the stone cast; and wherein the portion of the second point cloud dataset was scanned from the forming surface of the stone cast. The step of digitally scanning at least a first surface of the diagnostic wax-up may comprise the steps of digitally scanning both the first surface of the diagnostic wax-up and a first portion of the surface of the stone cast while said diagnostic wax-up is mounted on the stone cast; and creating a common point cloud dataset including points scanned from the first surface of diagnostic wax-up and points scanned from the first portion of the surface of the stone cast. The step of digitally registering the first and second point cloud datasets may comprise the step of digitally registering the points scanned from the first portion of the surface of the stone cast in the common point cloud dataset, and points scanned from the stone cast in the second point cloud dataset. A common portion of the stone cast surface may define both the points scanned from the surface of the stone cast in the common point cloud dataset and the points scanned from the stone cast in the second point cloud dataset. The step of digitally registering the first and second point cloud datasets may comprise the step of registering points in both the first and second point cloud datasets taken from the common portion of the stone cast surface.

In accordance with a tenth aspect of the invention, a method of creating a digital model of a dental prosthesis of a patient from an impression of the patient's mouth, a stone cast of the impression, and a diagnostic wax-up formed on the stone cast is provided, the method comprising the steps of digitally scanning at least a first surface of the diagnostic wax-up to form a first point cloud dataset; digitally scanning at least a second surface of the stone cast to form a second point cloud dataset; and digitally registering the first and second point cloud datasets.

The step of digitally registering may comprise the steps of digitally registering a portion of the first point cloud dataset with a portion of the second point cloud dataset; wherein the portion of the first point cloud dataset was scanned from a portion of the diagnostic wax-up formed by a forming surface of the stone cast; and wherein the portion of the second point cloud dataset was scanned from the forming surface of the stone cast. The step of digitally scanning at least a first surface of the diagnostic wax-up may comprise the steps of digitally scanning both the first surface of the diagnostic wax-up and a first portion of the surface of the stone cast while said diagnostic wax-up is mounted on the stone cast; and creating a common point cloud dataset including points scanned from the diagnostic wax-up and points scanned from the first portion of the surface of the stone cast. The step of digitally registering the first and second point cloud datasets may comprise the step of digitally registering the points scanned from the first portion of the surface of the stone cast in the common point cloud dataset, and points scanned from the stone cast in the second point cloud dataset. A common portion of the stone cast surface may define both the points scanned from the surface of the stone cast in the common point cloud dataset and the points scanned from the stone cast in the second point cloud dataset. The step of digitally registering the first and second point cloud datasets may comprise the step of registering points in both the first and second point cloud datasets taken from the common portion of the stone cast surface.

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In accordance with an eleventh aspect of the invention, a method of creating a digital model of a dental prosthesis of a patient from an impression of the patient's mouth, a stone cast of the impression, a diagnostic wax-up formed on the stone cast, and a putty index formed on the diagnostic wax-up and the stone cast is provided, the method comprising the steps of digitally scanning at least a first surface of the putty index to form a first point cloud dataset; digitally scanning at least a second surface of the stone cast to form a second point cloud dataset; and digitally registering the first and second point cloud datasets.

The step of digitally registering may comprise the steps of digitally registering a portion of the first point cloud dataset with a portion of the second point cloud dataset; wherein the portion of the first point cloud dataset was scanned from a portion of the putty index formed by a forming surface of the stone cast; and wherein the portion of the second point cloud dataset was scanned from the forming surface of the stone cast. The step of digitally scanning at least a first surface of the putty index may comprise the steps of digitally scanning both the first surface of the putty index and a first portion of the surface of the stone cast while said putty index is mounted on the stone cast; and creating a common point cloud dataset including points scanned from the putty index and points scanned from the first portion of the surface of the stone cast. The step of digitally registering the first and second point cloud datasets may comprise the step of digitally registering the points scanned from the first portion of the surface of the stone cast in the common point cloud dataset, and points scanned from the stone cast in the second point cloud dataset. A common portion of the stone cast surface may define both the points scanned from the surface of the stone cast in the common point cloud dataset and the points scanned from the stone cast in the second point cloud dataset. The step of digitally registering the first and second point cloud datasets may comprise the step of registering points in both the first and second point cloud datasets taken from the common portion of the stone cast surface. The impression may comprise a plurality of copings. The method may further comprise the step of fixing a plurality of surface extensions to the plurality of copings. The step of digitally scanning at least the second surface may comprise the step of digitally scanning surfaces of the plurality of surface extensions. The stone cast may comprise a plurality of analogs. The method may further comprise the step of fixing a plurality of surface extensions to the plurality of analogs. The step of digitally scanning at least the second surface may comprise the step of digitally scanning surfaces of the plurality of surface extensions.

In accordance with a twelfth aspect of the invention, a method of preparing a denture for a patient is provided, the method comprising the steps of coupling a plurality of fittings to a plurality of analogs embedded in a stone cast of the patient's maxilla or mandible; forming a diagnostic wax-up on the stone cast in which the plurality of fittings are embedded; removing the diagnostic wax-up with embedded fittings from the stone cast; fixing surface extensions to each of the plurality of fittings; sequentially scanning a plurality of points on the surface of the diagnostic wax-up and on the surface extensions to generate a point cloud dataset; and, for each of the fittings represented in the point cloud dataset, deriving from the points scanned from the surface extension of that fitting a desired location and orientation of a corresponding mount configured to engage the analog on which that fitting was mounted.

In accordance with a thirteenth aspect of the invention, a method of creating a dental framework having a plurality of mating surfaces that are configured to engage corresponding

plurality of anchors in a patient's mouth, is provided the method comprising the steps of: attaching a plurality of copings to the anchors; forming an impression in which the copings are embedded; attaching an analog to each of the plurality of copings; forming a stone cast in which the plurality of copings are embedded; attaching alignment posts having surface extensions to each of the analogs; digitally scanning the surface extensions to generate a point cloud dataset; deriving the relative positions and orientations of the mating surfaces from the point cloud dataset; generating a toolpath that is configured to generate the mating surfaces in their relative positions and orientations; and making the framework in accordance with the toolpath.

The alignment posts may be attached to surfaces of the analogs that correspond to the plurality of mating surfaces on the anchors. The framework may further comprise a bridging structure that extends between and couples the plurality of mating surfaces together, and the step of generating a toolpath may further comprise the step of generating a toolpath configured to generate the bridging structure. The step of digitally scanning the surface extensions may further comprise the step of scanning the surface extensions with a laser scanner at a plurality of locations on each surface extension to produce a plurality of three dimensional datapoints, said point cloud dataset comprising the three dimensional datapoints. The step of deriving the relative positions and orientations may further comprise the step of electronically fitting datapoints scanned from the surface extensions to a predetermined three dimensional geometry of the surface extensions stored in a computer memory.

In accordance with a fourteenth aspect of the invention, a method of generating a toolpath for manufacturing a dental framework for a patient's mouth is provided, the patient's mouth comprising a plurality of anchors embedded in the patient's mandible or maxilla, the framework being made from a stone cast with embedded analogs, the stone cast being made from an impression having embedded copings, the impression being taken directly from the patient's mouth, wherein the framework further comprises a plurality of mating surfaces that are configured to engage the plurality of anchors, the method comprising the steps of: attaching alignment posts having surface extensions to each of the analogs embedded in the stone cast of the patient's mouth; digitally scanning the surface extensions to generate a point cloud dataset; deriving the relative positions and orientations of the mating surfaces from the point cloud dataset; and generating a toolpath that is configured to generate the mating surfaces in their relative positions and orientations.

In accordance with a fifteenth aspect of the invention a method of creating a dental framework having a plurality of mating surfaces that are configured to engage a corresponding plurality of anchors in the patient's mouth is provided, the method comprising the steps of: attaching a plurality of copings to the anchors; forming a stone cast in which the copings are embedded; attaching an analog to each of the plurality of copings; forming a stone cast in which the plurality of analogs are embedded; attaching a fitting to each of the plurality of analogs; coupling the fittings together with a bridging structure to hold them in their relative positions thereby forming a model framework; removing the fittings and bridging structure from the copings; attaching alignment posts having surface extensions to each of the fittings; digitally scanning the surface extensions to generate a point cloud dataset; deriving the relative positions and orientations of the mating surfaces from the point cloud dataset; generating a toolpath that is

configured to generate the mating surfaces in their relative positions and orientations; and making the framework in accordance with the toolpath.

The alignment posts may be attached to surfaces of the fittings that correspond to the plurality of mating surfaces on the anchors. The step of digitally scanning further may comprise the step of digitally scanning the surface of the bridging structure to generate the point cloud dataset, and the step of generating a toolpath may comprise the step of generating a toolpath configured to generate the bridging structure from datapoints scanned from the surface of the bridging structure. The step of digitally scanning the surface extensions may comprise the step of scanning the surface extensions with a laser scanner at a plurality of locations on each surface extension to produce a plurality of three dimensional datapoints, the point cloud dataset comprising the three dimensional datapoints. The step of deriving the relative positions and orientations may comprise the step of electronically fitting datapoints scanned from the surface extensions to a predetermined geometry of the surface extensions stored in a computer memory.

In accordance with a sixteenth aspect of the invention, a method of creating a dental framework having a plurality of mating surfaces that are configured to engage a corresponding plurality of anchors in the patient's mouth, the method comprising the steps of: attaching a plurality of copings to the anchors; forming a stone cast in which the copings are embedded; attaching an analog to each of the plurality of copings; forming a stone cast in which the plurality of analogs are embedded; attaching a fitting to each of the plurality of analogs; coupling the fittings together with a bridging structure to hold them in their relative positions thereby forming a model framework; removing the fittings and bridging structure from the copings; attaching alignment posts having surface extensions to each of the fittings; digitally scanning the surface extensions to generate a point cloud dataset; deriving the relative positions and orientations of the mating surfaces from the point cloud dataset; generating a toolpath that is configured to generate the mating surfaces in their relative positions and orientations; and making the framework in accordance with the toolpath.

In accordance with the 17th aspect of the invention, a method of locating a dental appliance with respect to dental surfaces is provided, the method comprising the steps of: scanning a first dental surface to create a first point cloud dataset; scanning a second dental surface to create a second point cloud dataset; registering the first and second point cloud datasets by aligning points in each dataset taken from the overlapping surface portions; and using non-overlapping portions of both point cloud datasets to define the location of the dental appliance.

The first dental surface and the second dental surface may be selected from the group comprising an impression, a stone cast, a diagnostic wax-up, a facial index and a dental framework. Not second dental surface is selected from the group comprising an impression, a stone cast, a diagnostic wax-up, a facial index, and a dental framework. The first point cloud dataset may comprise both points scanned from a surface of a diagnostic wax-up disposed on a stone cast and points scanned from a surface of the stone cast while the diagnostic wax-up is disposed on it, and the second point cloud dataset may comprise points scanned from the surface of the stone cast and points scanned from a surface of the stone cast that was covered by the diagnostic wax-up when the diagnostic wax-up was scanned to create the first point cloud dataset, and the portions of the stone cast common scanned to both point cloud datasets may constitute the overlapping portions of

both point cloud datasets. A facial index may have a first surface formed in abutment to a diagnostic wax-up and a second surface formed in abutment to a third surface of a stone cast, the first point cloud dataset may comprise points scanned both from the first surface and the second surface, and the second point cloud dataset may comprise points scanned from the third surface and points scanned from a fourth surface of the stone cast adjacent to the third surface, and the overlapping portions of both point cloud datasets may comprise points scanned from the second surface in the first point cloud dataset and points scanned from the third surface in the second point cloud dataset.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a fragmentary cross sectional view of an anchor embedded in a mandible.

FIGS. 2A and 2B are perspective views of a two piece coping to be attached to the anchor of FIG. 1.

FIG. 3 is a perspective view of anchor with coping attached.

FIG. 4 is a fragmentary perspective view of a patient's open mouth with the anchors embedded in the patient's mandible.

FIG. 5 is a fragmentary perspective view of the patient's open mouth with several copings attached to the anchors and an impression tray with impression material surrounding the patient's mucosal tissue and submerging the copings.

FIG. 6 is a perspective view of the impression of FIG. 5 inverted and removed from the patient's mouth with two analogs attached to two of the copings.

FIG. 7 is the same perspective view of FIG. 6, but with all the analogs attached to all the copings, and the impression filled with dental stone material and all the analogs submerged in the dental stone material.

FIG. 8 is a perspective view of the stone cast formed by the dental stone material poured in the impression of FIG. 7 in its hardened state, inverted, and with the impression removed showing the analogs with the analog surfaces that mated with the copings (in FIG. 7 now exposed).

FIG. 9 is a perspective view of the stone cast of FIG. 8 with the dentist's manufactured diagnostic wax-up that was previously built up on the top of the mandible now disposed on the stone cast and abutting the analogs.

FIG. 10 is a cross-sectional view of the stone cast of FIG. 9 taken at section line 10-10 in FIG. 9.

FIG. 11 is a perspective view of the stone cast of FIGS. 8-10, with a putty index molded to the facial aspect of the diagnostic wax-up.

FIG. 12 is a cross sectional view of the stone cast of FIGS. 8-11 taken at section line 12-12 in FIG. 11.

FIG. 12B is a cross sectional view of the stone cast of FIGS. 8-12 with the diagnostic wax-up removed to show the inner surface of the putty index and the impression of the facial aspect of the diagnostic wax-up formed on the inner surface of the putty index.

FIG. 13A is a perspective view of the stone cast of FIGS. 8-12B with six fittings, one fitting attached to each of the six analogs.

FIG. 13B is a perspective view of the stone cast of FIGS. 8-13A with bridging structures fixed to and between each of the six fittings to form a wax-up framework mounted on the six analogs.

FIG. 13C is a bottom view of the wax-up framework of FIGS. 13A-13B as it would appear when removed from the stone cast and inverted.

FIG. 14 is a perspective view of the removed wax-up framework of FIG. 13C with an alignment post attached to each of the six fittings.

FIG. 15 is a cross sectional view of the wax-up framework of FIG. 14 with alignment posts attached taken along the longitudinal axis of either one of the two end alignment posts and its associated fitting.

FIG. 16 is a cross sectional view of the wax-up framework of FIG. 14 with alignment posts attached taken along the longitudinal axis of any one of the four central alignment posts and its associated fitting.

FIG. 17 is a side view of either one of the two end alignment posts (two-piece) of FIGS. 14-15 showing the fitting in which it is fitted in phantom lines.

FIG. 18 is a side view of any one of the four central one-piece alignment posts of FIGS. 14, 16.

FIG. 19 is a schematic diagram of the scanner and the wax-up framework and alignment posts of FIG. 14 that it is scanning.

FIG. 20 is a flow chart of the process of scanning and manufacturing the framework of FIGS. 13A-14 with alignment posts attached as shown in FIGS. 14-16.

FIG. 21 is a graphical representation of the surface model scanned from the wax-up framework plus alignment post assembly of FIGS. 14 and 19 with the alignment posts subsequently digitally removed.

FIG. 22 is a graphical representation of the surface model of FIG. 21 with pads.

FIG. 23 is a graphical representation of the surface model of FIG. 22 with parameterized fitting sunk into the pads configured to be mounted to the anchors.

FIG. 24 is a flow chart of the process of manufacturing a denture framework from a scan of the stone cast shown in FIGS. 8-13B but with alignment posts attached to it—and optionally a scan of the diagnostic wax-up and/or the putty index of FIGS. 9-12B.

FIGS. 25-27 are three different perspective views of a mathematical surface model of a denture framework generated by the scanner of FIG. 19.

FIG. 28 is a perspective view of a diagnostic wax up formed on the surface of a stone cast with embedded fittings.

FIG. 29 is a perspective view of the wax-up of FIG. 28 removed from the stone cast with the fittings embedded in the diagnostic wax-up and alignment posts fixed to the now-free surfaces of the fittings.

FIG. 30 is a perspective view of an impression with coping extending therefrom to which alignment posts have been attached.

FIGS. 31-36 are side and end views of alternative alignment posts.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In FIG. 1, the patient's jaw or mandible 100 can be seen overlaid with soft mucosal tissue 102 (known commonly as "gum tissue"). An anchor 104, also known as an "implant" or "fixture" is shown embedded into the patient's mandible 100. This anchor is retained within the mandible by a screw thread 106. It is driven into the mandible 100 by coupling a wrench or similar device to the top of the anchor 104 and rotating the wrench to drive the anchor into the jaw bone just as one would drive a screw into a piece of wood. In an alternative embodiment, the anchor 104 is press fitted into a hole formed with a drill, reamer, broach, osteotome, or similar device.

FIG. 1 illustrates the first step in the process, that of forming an opening in the mandible of the patient and fixing an

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anchor therein, while leaving a top surface of the anchor exposed above mucosal tissue **102** for mating (coupling) to and supporting a dental prosthesis or restorative component such as a denture, bridge, crown, framework, abutment, healing cap, or coping (hereinafter referred to as “denture”). Note that while the process illustrated herein describes and illustrates a mandible for illustration purposes, the same process is performed to embed anchors **104** into the patient’s maxilla and create dental prostheses for the maxilla.

To attach anchors **104**, the dentist first makes an incision in the mucosal tissue **102** where a missing tooth or teeth would normally extend from the mandible where it is embedded, through the gum, and into the oral cavity. Once the incision is made, the dentist makes a hole (which may include such processes as drilling, broaching or reaming) in the mandible **100** in the same general direction and location as the missing tooth. The dentist then fixes an anchor **104** into the hole thus created and sutures the incision, typically leaving mating surface **108** of anchor **104** exposed while the bone osseointegrates to the outer surface of anchor **104**. Alternatively, the dentist may attach a healing cap to the anchor **104** and suture the gum around or over the top of the anchor **104** and the healing cap, permitting the gum to heal around or over the top of the anchor **104** as it osseointegrates. In this alternative process, once the anchor has osseointegrated, the dentist incises the mucosal tissue **102** extending over the top of the now-integrated anchor **104** and retracts the mucosal tissue to each side, exposing the mating surface **108** of anchor **104** and permitting the mucosal tissue to heal.

The anchor **104** has a central longitudinal aperture **107** in the top which is configured to receive an impression coping **110** (FIG. 2) (or a fastener configured to mount the impression coping **110**) that is affixed to the anchor **104**. This coping transfers the size, shape, location or orientation of the mating surface **108** of the anchor (and preferably all four) to the stone cast (see below). It is the mating surface **108** that is oriented to the finished denture, and hence the mating surface **108** from which the structures of the denture that mount to the anchors are derived. For convenience of illustration in FIG. 1 only a single anchor **104** is shown. In practice, anywhere from one to twelve of these anchors are embedded in the maxilla and are provided as mounting points for the denture. In an alternative configuration, anchor **104** may have a variety of configurations on its mating surface **108** including threaded or unthreaded protrusions or recesses that are configured to engage a denture. The use of an anchor **104** having a central aperture and internal threads for engaging a coping is a matter of convenience herein and should not suggest that the process is limited to an anchor having this configuration.

FIGS. 2A, 2B and 3 illustrate an impression coping **110** that is configured to be fixed on to the mating surface **108** of anchor **104**. In the second step of the process, the dentist fits anchor **104** with a coping **110** that is aligned to surface **108** (FIG. 1). Mating surface **108** is typically the surface on which the denture will be mounted or a surface having a predetermined position with respect to that surface on which the denture will ultimately be mounted. The coping **110** is configured to engage surface **108** and surrounding structures of anchor **104** (if any) such as holes that extend into (or protrusions that extend above) the surface **108**.

These interengaging surfaces of coping **110** and anchor **104** serve to align the coping and the anchor in predetermined positions with respect to each other when fixed together, such that if one knows the position and orientation of surfaces on the coping one can know the position and orientation of corresponding structures on the anchor **104** and more preferably when a scanner (see below) determines the position and

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orientation of structures on copings **110** it can mathematically determine the position and orientation of corresponding structures on anchors **104**. Anchor **104** is preferably cylindrical and has a longitudinal axis **111**, as does coping **110**. In a typical arrangement, when the coping **110** is fixed in its predetermined position with respect to anchor **104**, a longitudinal axis **111** of the coping is coaxial with the longitudinal axis of the anchor **104**. The coping **110** and the anchor **104** are preferably threadedly engaged to permit surfaces on the coping to be drawn down tightly against mating surface **108** for precise alignment of their interengaging surfaces. Alternatively, the coping **110** and anchor **104** to which it is coupled may be equipped with interengaging snap fastening connecting surfaces that hold the coping in the proper orientation with respect to anchor **104**.

FIG. 2A shows a tubular central portion **116** of coping **110** that is configured to be received in an outer sleeve portion **112** of the coping having a central longitudinal hole **114** shown in FIG. 2B.

Sleeve portion **112**, as shown in FIG. 3, abuts the soft mucosal tissue surrounding the mating surface **108** of anchor **104**, preventing the tissue from covering mating surface **108**. Tubular central portion **116** extends through outer sleeve portion **112** and is engaged to the central longitudinal aperture **107** formed in the end of anchor **104** (see FIG. 1). This is the preferred form of the coping **110**, and the preferred means for attaching the coping to anchor **104**. It is not the only means, however.

FIG. 4 illustrates the mandible **100** of FIGS. 1, 2A, 2B, and 3, with all the anchors **104** implanted in the mandible, and ready for the next step in the process. In this FIGURE, the edentulous mandible **100** has six anchors **104** affixed therein in a spaced-apart relation extending from the front of mandible **100** around each side. The anchors **104** are disposed in a generally upright and parallel relation extending into the top surface of mandible **100**. The dentist attaches corresponding copings **110** to the top of each anchor **104** and extends upward in a generally upright and parallel relation to the other copings **110**. The application illustrated herein shows the use of six anchors configured to support a denture. Other applications with more or fewer anchors **104** are possible. Furthermore, the mandible need not be edentulous (shown here), but may have, and often does have, a few natural teeth remaining in the maxilla or mandible between which the anchors **104** are embedded to support one or more dentures (such as fixed or removable partial dentures) to fill the gap or gaps between the existing natural teeth. In this case, the anchors would not be spaced evenly about the mandible, as shown here, but would be spaced irregularly in the gaps created by the absence of natural teeth.

FIG. 5 illustrates the next step in the process of creating a denture, the step of creating an impression of the patient’s mandible. This FIGURE shows an impression tray **120** filled with flexible impression material **122**. The tray is a semi flexible plastic structure that holds the impression material **122** in position around the patient’s teeth (if any) and mucosal tissue. FIG. 5 shows a tray **120** for the lower teeth surrounding teeth, mucosal tissue, and mandible of the patient.

The copings **110** previously attached by the dentist to the anchors **104** are completely submerged by the dentist in impression material **122** such that the entire outer surfaces of the copings **110** extending above the surface of the mucosal tissue on the patient’s mandible **100** are completely covered. The impression material is left in this position to cure. Once cured, the individual copings **110** are fixed with respect to each other in the same position and orientation that the anchors **104** are fixed with respect to each other. The curing

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process fixes the copings in this position and thereby permits the copings to be collectively removed together with the impression material while preserving their orientation.

In the next step of the process, the dentist flexes the tray **120** and the now-cured impression material **122** and removes them from the patient's mouth. Enough impression material **122** is placed in the tray and disposed around the patient's mandible **100** to cover any still-existing teeth of the mandible and the mucosal tissue **102** of the mandible as well as the copings **110**.

When the tray **120** and impression material **122** are removed, the copings are removed with them, embedded in the now-cured impression material **122**. The process of removal disconnects the copings **110** from the anchors **104**, permitting the copings to be removed while still embedded in the impression material **122**. If the copings include a threaded portion that holds them to the anchors, this threaded portion is unthreaded from the anchors. If the copings are fastened to the anchors with a snap fastening portion, the snap fastening portions are unsnapped from each other. The now-cured impression material **122** that couples the copings **110** to each other preserves the relative positions and orientations of the mating surfaces of all the copings **110** and hence relative positions and orientations of the mating surfaces **108** of all the anchors **104** with respect to each other. This relationship is preserved in the relative positions and orientations of the surfaces of copings **110** that were connected to the mating surfaces **108** of anchors **104**. The impression material **122** in which copings **110** are embedded also preserves the surface contours of the mucosal tissue and the remaining teeth (if any) in the mandible and their relative positions with respect to the mating surfaces of copings **110** and anchors **104**. The surface of the impression material **122**, once removed from the patient's mouth, is a negative replica of the soft tissue and teeth. The surfaces of copings **110**, now separated from anchors **104** and exposed on the inside surface of the impression material **122**, are a negative replica of surfaces **108** of anchors **104** to which they were coupled. The now-cured impression material **122** is therefore a negative replica of all the free surfaces, including teeth, mucosal tissue, and the surfaces of the copings embedded in the impression material are a negative replica of the mating surfaces **108** of anchors **104**. The cured impression material with embedded copings is commonly called an "impression" and identified in the FIGURES herein as item **123**.

FIG. **6** shows the impression **123** inverted and removed from the patient's mouth. In this embodiment, there are six copings **110** embedded in the impression **123**. The bulk of the copings **110** are embedded in the impression **123**. Only the very ends of the copings **110** extends upward and out of the impression **123** (in this inverted orientation).

In FIG. **6** the dentist has begun the next step of the process, that of attaching analogs **124** to the exposed surfaces of all of the copings **110**. Analogs **124** are structures that replicate the anchors **104**. As in the case of the copings themselves, each analog **124** preferably comprises a generally cylindrical body with a longitudinal axis **127** that is coaxial with the longitudinal axis **111** when attached to coping **110**.

The end surfaces of analogs **124** are configured to abut and mate with the free surfaces of the copings **110** that were previously coupled to anchors **104**. The surfaces of analogs **124** replicate the position and orientation of mating surfaces **108** of anchors **104**. In effect, the spacing and orientation of anchors **104** was transferred to the copings **110**, and transferred back again to analogs **124**, which have the same spac-

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ing and orientation as the anchors **104**. Thus, each analog **124** is coaxial with and is disposed in the same position as anchor **104**.

In the next step of the process, illustrated in FIG. **7**, the dentist pours a mixed dental stone material **126** into the cavity in impression **123** that was formed by the patient's mandible, submerging all of the analogs **124**. Stone material **126** covers the exposed portion of the analogs **124** as well as the surfaces of impression **123** formed by the patient's mucosal tissues and teeth. Once filled into impression **123**, the stone material **126** is then permitted to harden to a rock-like consistency, creating a structure that is called a "stone cast" **125**.

FIG. **8** represents the next step of the process which the dentist performs once the stone material **126** has hardened. The dentist removes impression **123** from the stone cast **125**, leaving the stone cast **125** with the analogs embedded therein. The stone cast **125** positively replicates the position and orientation of mating surfaces **108** of anchors **104**, which are represented in the stone cast **125** by the mating surfaces **128** of the analogs **124** that were fixed to the free ends of copings **110** (FIG. **6**). The portions of the stone cast **125** surrounding analogs **124** positively replicates the surface of the mucosal tissues of the mouth, which were transferred from the mucosal tissues of the mouth to the impression as a negative replica and then back to the stone cast as a positive replica of those tissues. The stone cast **125** also replicates the surface of the patient's existing teeth (not shown). When the patient has existing teeth, the position and orientation of the surfaces of the teeth are transferred first to the impression as a negative replica and then to the stone cast as a positive replica. In the present embodiment, the mandible **100** is edentulous and therefore there are no existing teeth.

As will be explained later, teeth that are replicated in impression **123** and stone cast **125** provide a precise reference to indicate the location of the jawbone. The soft tissues that are replicated in the impression **123** and stone cast **125** can change their position due to swelling, edema, injury, irritation, or damage to the mouth. Teeth, since they are much harder and are embedded in the jawbone, provide a more stable reference, over time, of the position of the jawbone and thus indirectly, of the position and orientation of anchors **104**.

The impression molding and stone casting processes described above provide accurate replicas of the position and orientation of the mating surfaces **108** of anchors **104**, the mucosal tissues, and the teeth.

In the preferred embodiment, the mating surfaces **108** of anchors **104** are exactly duplicated by the mating surfaces **128** of the analogs **124**: they are in exactly the same position and at exactly the same orientation. In an alternative embodiment, the mating surfaces **128** on the analogs may be offset slightly or configured slightly differently than the mating surfaces **108** of anchors **104**. In some cases, manufacturers choose to make analogs or other connecting components that have mating surfaces slightly different from the mating surfaces **108** of the anchors **104** for example to permit the copings **110** to be more easily attached to anchors **104** or to permit analogs **124** to be more easily attached to copings **110**. Any slight difference in position such as this is intentional, however, and is eliminated later in the process when the denture is created so that the mating surfaces of the denture are precisely oriented to mate properly with surfaces **108** of anchors **104** in the patient's mouth.

Further, the anchors **104** in the patient's mouth may not be connected directly to the dental framework. Abutments may be mounted on the anchors **104** (i.e. the anchors have surmounted abutments). The dental framework may be mounted to these abutments, and thus indirectly mounted to anchors

104. When the dental framework being designed is intended to be mounted on abutments mounted on anchors **104**, the analogs **124** may be provided with surmounted abutments, i.e. the analogs may include the abutment design incorporated into it, to replicate the mating structure of the abutment to the framework.

While the mating surfaces **128** of the analogs **124** and the mating surfaces **108** of anchors **104** may be slightly differently configured, the longitudinal axes of each of the anchors **104** and the analogs **124** are preferably identically oriented and spaced apart, each pair of corresponding analog and anchor sharing a common longitudinal axis (i.e. they are coaxial). Considered differently, if the surface of the stone cast representing the soft tissues and teeth of the patient's mouth could be superimposed on top of the patient's mucosal tissues **108** that formed the stone cast **125**, all the longitudinal axes defined by the analogs would be superimposed on (i.e. simultaneously coaxial with) all the corresponding axes defined by the anchors. The longitudinal axes **127** of the analogs **124** and the surfaces of the stone cast **125** defined by the mucosal tissues **108** the patient are positive replicas of the longitudinal axes **111** of anchors **104** and the surfaces of mucosal tissues **108**.

The replica of any teeth formed in the surface of the stone cast are formed with respect to one another and with respect to the analogs such that they duplicate the position of any existing real teeth in the patient's mouth with respect to one another and with respect to mating surfaces **108** and longitudinal axes of the anchors **104** in the patient's mandible. The replica of the mucosal tissues formed in the surface of the stone cast are in generally the same position on the stone cast as they are in the patient's mouth including the replication in the stone cast **125** of the junction between the mucosal tissue and any existing teeth and anchors **104**, as well as a replication in the stone cast of all the mucosal tissue that will be covered by the denture.

Once the dentist has created the stone cast **125**, which is a positive replica of the patient's jaw, including replication of existing teeth, mucosal tissue, and anchors, the dentist then proceeds to the next step in the process: designing and creating the denture that will be fitted to the patient's mouth (in this case, the patient's jaw).

The dentist manually creates a diagnostic wax-up **130** of the desired denture teeth position and occlusal orientation, using flexible molding materials such as wax, acrylic, and other polymers.

The diagnostic wax-up **130** is created to verify the proper location of the denture mucosal tissue and denture teeth with respect to the patient's actual mouth to ensure proper tooth orientation, and to ensure that the location and placement of the denture within the patient's mouth restores form, fit and function. In short, the diagnostic wax-up **130** is a model of and looks like the denture that is ultimately produced, but is made of softer materials to permit it to be adjusted and adapted until the patient and dentist are pleased with its form, fit and function.

The dentist creates the wax-up **130** on the stone cast, building it up on the patient's replica mucosal tissue. When the dentist is finished making the wax-up **130**, he removes the wax-up **130** from the stone cast **125**, and places it into the patient's mouth so the patient can see, firsthand, what the denture will look like when it is finished. If the wax-up **130** fits, the patient can bite properly, and the patient is pleased with the appearance of the wax-up **130**, the dentist then proceeds to manufacture the denture.

FIGS. 9-10 illustrate the process of creating a wax-up, showing the stone cast **125** as it would appear with a wax-up

130 modeled on its outer surface. In FIG. 9, the stone cast **125** is shown covered with the wax-up **130** which comprises the denture teeth **132** embedded in wax **134** which the dentist has molded directly to the surface of the stone cast **125**. FIG. 10 is a cross-sectional view through the stone cast **125** plus wax-up **130** assembly shown in FIG. 9. This cross-section is taken at section line 10-10 in FIG. 9.

Once the dentist has created the wax-up **130** and has verified the fitting of the wax-up **130** in the patient's mouth, he then proceeds to the next step in the process, which is illustrated in FIGS. 11-12. In this step, he removes the wax-up **130** from the patient's mouth, and places it back on stone cast **125**. He then creates a negative replica **142** of the facial form of wax-up **130** called a "putty index" (or as it is alternatively and equivalently called: a "facial index").

To create the putty index **142**, the dentist molds silicone putty **144** directly to the facial surface of wax-up **130** including the teeth **132** and the wax **134** that represents the artificial mucosal tissue portion of the denture. This silicone putty **144** extends beyond the edges of wax-up **130** to the adjacent surfaces of stone cast **125**.

FIG. 11 shows the silicon putty, already solidified, surrounding the wax-up **130** on stone cast **125**. FIG. 12 is a cross-section through the stone cast/wax-up/silicon putty of FIG. 11, taken at section line 12-12 in FIG. 11. Referring now to FIG. 12, we can see that silicon putty **144** has been manually molded on to the surface of the stone cast **125** adjacent to wax-up **130**, at junction **145**, for example.

In the next step, the dentist removes the now-solidified silicon putty **144** (i.e. putty index **142**) from the stone cast **125** and wax-up **130**, removes the wax-up **130** from the stone cast **125** and replaces the putty index **142** on the stone cast **125** in its original position, as shown in FIG. 12B.

This removal creates an outline form **147** formed on the inner surface of the putty index **142** that is the exact size and shape of the facial aspect of the wax-up **130**. Outline form **147** is a negative replica of the teeth **132** of wax-up **130**, the mucosal tissue formed in wax **134** that surrounds and supports the teeth **132**.

When forming the putty index **142**, the dentist extends the silicone putty **144** beyond the edge of the wax-up at junction **145** and abuts the stone cast **125** to form a direct junction between the putty index **142** and the stone cast **125**. This abutting relationship molds the two surfaces together and permits the dentist to orient the putty index **142** in its as-formed position with respect to stone cast **125**. The dentist does this by aligning surfaces **146** of the putty index **142** that were molded in abutment to surfaces **148** of the stone cast **125**. Surface **148** is a negative replica of surface **146**.

As in the case of many irregular surfaces, such as the mating broken edges of two pieces of pottery, a surface portion of stone cast **125** mates with the surface on putty index **142** on which it was formed to define a very precise assembled orientation that is easy to recreate once wax-up **130** is removed.

With the putty index **142** created, the dentist can proceed to the next step in the process, illustrated in FIGS. 13A, 13B, in which the dentist molds a wax-up framework **150**. Wax-up framework **150** is later duplicated in metal and embedded in the plastic body of the denture to support the denture on anchors **104** in the patient's mouth.

With the putty index **142** removed, the dentist fixes precision copings or fittings **152** that are typically provided by the manufacturer of analogs **124** and are configured to mate with the analogs. These are shown in the FIGURES as items **152A-152F** and are attached to the mating surfaces **128** of analogs **124** extending from stone cast **125** (FIG. 13A). The analogs

124 embedded in stone cast **125** orient fittings **152** precisely with respect to one another to replicate the position and orientation of anchors **104**. In short, the stone cast holds fittings **152** in the same position with respect to each other in which they would be held by anchors **104** if they were inserted into the patient's mouth instead of being fastened to the analogs **124**.

Referring now to FIG. **13B**, once the dentist has attached fittings **152** to analogs **124**, he then proceeds to create a bridging structure **154** of the framework **150**. Bridging structure **154** is typically formed from a moldable wax/acrylic material. The dentist manipulates this material and extends it as a narrow band adjacent to the surface of stone cast **125** until each of the fittings **152** are coupled together with bridging structure **154** (FIG. **13B**) to form a single structure.

The dentist must verify the wax-up framework **150** before he can cast it in metal, however. In order to verify the wax-up framework **150**, the dentist must fit the putty index **142** (whose outline form **147** negatively replicates the position and orientation of the facial surface of diagnostic wax-up **130** and thus the facial surface of the denture) to ensure that wax-up framework **150** is enclosed within the putty index where desired, and therefore will be embedded within the denture material when the denture is finally created. Portions of the wax-up framework **150** may be deliberately designed to extend outside of the denture and reach remote anchors **104** to provide additional stability. Typically, however, the framework is completely embedded within the denture material that replicates the mucosal tissue. By testing the shape of the framework (typically by repeatedly placing and removing the putty index from the stone cast **125** in front of the wax-up framework **150**) as the dentist builds the framework, the dentist can build and adjust the bridging structure **154** of the framework until it is disposed well back from the outline form **147** of the putty index in a position where it will provide the most support for the denture teeth and the denture gum material that supports the denture teeth.

FIG. **13B** illustrates stone cast **125** with wax-up framework **150** including bridging structure **154** extending across the surface of the stone cast **125** and coupling together all of the fittings **152** coupled to the mating surfaces **128** of analogs **124** that extend outward from the stone cast **125**. In the next step, the dentist detaches the wax-up framework **150** from stone cast **125**.

FIG. **13C** illustrates wax-up framework **150** as it would appear detached from stone cast **125** and inverted, exposing surfaces of fittings **152** that mate with analogs **124**. Fittings **152** include two fittings **152A**, **152B** that have cylindrical or frusto-conical recesses **159** with apertures **158** extending completely through fittings **152** and wax-up framework **150**. Apertures **158** are configured to receive screws that are attached to anchors **104** in the patient's jaw. The other four fittings **152C**, **152D**, **152E**, **152F** do not have apertures **158** but do have cylindrical or frusto-conical recesses **159** common to all the fittings **152**. They are configured to be supported on mating cylindrical or frusto-conical posts (not shown) that will be an integral part of anchors **104** or that will be attached to the anchors **104**. In the illustrated embodiment the two rear fittings **152A**, **152B** are configured to be fixed to anchors with screws passing through apertures **158**. In an alternative embodiment, any of the other fittings **152** (or none, or all) may be provided with apertures or other means for attaching the fittings **152** to anchors **104**.

It should be remembered that wax-up framework **150**, fittings **152** and bridging structure **154** are never intended to be mounted to anchors **104** in the patient's mouth. Instead, a duplicate is made of wax-up framework **150** out of much

stronger materials that is inserted in the patient's mouth. It is the duplicates of fittings **152** in the final framework that actually mount to anchors **104**.

For that reason, in order for the duplicates of fittings **152** formed in the final framework to mount properly to anchors **104** in the patient's mouth, fittings **152** themselves must be configured to mount to anchors **104**. If they are not configured to mount to anchors **104**, then their duplicates in the final framework will not mount to anchors **104**.

To configure the fittings **152** for mounting to the patient's jaw, each of fittings **152** illustrated in the FIGURES has at least one surface portion configured to mate with anchors **104**. Thus, the final framework can be fixed to analogs **124**. Since analogs **124** are mounted to and axially oriented to copings **110** (FIG. **13A**), and since copings **110** were initially fixed to and coaxial with anchors **104**, fittings **152** are configured to be fixed to and coaxial with anchors **104**.

Each mating surface on fittings **152** is symmetric about a longitudinal axis that extends through that fitting and are coaxial with the analogs **124** on which they are mounted. In this case, the surfaces are those interior to frusto-conical recesses **159**. This should not suggest that the mating surfaces must have any particular shape or orientation. Generally speaking, the mating surfaces may be concave or convex, they may be conical, cylindrical, circular, or parabolic. Regardless of their shape, each fitting **152** has at least one mating surface that preferably defines a longitudinal axis, and more preferably each of the mating surfaces is a surface that is symmetric about that longitudinal axis. It is these surfaces when duplicated to create the metal framework that orient the metal framework with respect to anchors **104**. Hence the longitudinal axes defined by the mating surfaces of fittings **152** replicate the longitudinal axes of anchors **104**.

Once the dentist has created the wax-up framework **150**, he sends the wax-up framework **150** to a laboratory for further processing.

In the next step of the process, and referring to FIG. **14**, a technician inserts alignment posts **156** (shown in the FIGURES as items **156A**, **156B**, **156C**, **156D**, **156E**, **156F**) into fittings **152**. Alignment posts **156** engage the surfaces of fittings **152** that are configured to engage surfaces **108** of anchors **104**. Alternatively, they are inserted such that they abut other surfaces of fittings **152** that are not configured to engage anchors **104** but are in a known pre-determined position and orientation with respect to surfaces **108** of anchors **104**. Alignment posts **156** have a longitudinal axis that is preferably coaxial with fittings **152** when they are mounted to fittings **152**. Since they are coaxial with fittings **152**, they are also coaxial with anchors **104**. As described in the process above, anchors **104** transfer their position and orientation to copings **110**, which transfer their position and orientation to analogs **124**, which transfer their position and orientation to fittings **152**, which transfer their position and orientation to posts **156**. Thus posts **156** are coaxial with fittings **152**, analogs **124**, copings **110** and anchors **104**.

In the next step of the process, the surfaces of wax-up framework **150** and the alignment posts **156** are electronically scanned, preferably by a laser scanner or alternative devices such as an optical, light, touch probe, or CT scanner.

The scanner is configured to generate a plurality of three-dimensional position data or points that represent the three-dimensional coordinates of each scanned point on the surface of wax-up framework **150** and alignment posts **156**. The scanning process need not scan all points on the surface of wax-up framework **150**, nor does it need to determine each point on the surface with the same accuracy. The particular location of points on the surface of bridging structure **154**

may not be as critical as points on the surfaces of the fittings **152**. Points on the surfaces of fittings **152** represent points on the surfaces of the metal framework made from the wax-up framework **150**, including points that will mate with mating surfaces **108** of anchors **104**. The relative position of the mating surfaces of fittings **152** ultimately determine the quality of the denture fit and the loads placed on anchors **104**. In contrast to this, some error in determining the surface of bridging structure **154** can be tolerated more easily, since any errors in determining the surface of bridging structures **154** will be accommodated when the denture material is processed around the outside of the metal framework.

The alignment posts **156** are used to provide a more accurate determination of the position and orientation of the surfaces of fittings **152** that, when duplicated in metal will engage mating surfaces **108** of anchors **104**. The alignment posts provide several extension surfaces that have a predetermined orientation and location with respect to the mating surfaces of fittings **152** (and hence with respect to mating surfaces **108** of anchors **104**). The surface extensions provided on posts **156** preferably have a larger surface area than the mating surfaces of fittings **152** to which they are coupled. The surface extensions provided on posts **156** preferably have a well-defined geometry that, when scanned, provide scanner position data bearing a known spatial relationship to the mating surfaces on posts **156** that can be easily processed by a digital computer to generate a much more accurate estimation of the position of the mating surfaces of fittings **152** (and hence mating surfaces **108** of anchors **104** on which the denture will be mounted) than can be provided by directly scanning those surfaces of posts **156** directly with the scanner.

Each of anchors **104**, and its corresponding copings **110**, analogs **124**, and fittings **152** preferably share a common longitudinal axis about which their respective mating surfaces, whatever their shape, are revolved. To determine the orientation and position of the surfaces, and particularly to determine the orientation of the surfaces on fittings **152** that are configured to mate with mating surfaces **108** of anchors **104**, the scanner, or the computer processing the data provided by the scanner, determines (1) the orientation of that longitudinal axis in three dimensions, and the particular point along that longitudinal axis where the mating surfaces are located. The mating surfaces may have slightly different profiles, they may have slightly different surface contours, they may be disposed at different positions along the longitudinal axis. Nonetheless, they all bear a distinct, repeatable, and predetermined position and orientation with respect to each other.

In FIG. **15**, alignment post **156A** is preferably made of two separate structures (shown as post portions **1000**, **1002**) that are inserted into opposite sides of aperture **158**. Post portions **1000**, **1002** of alignment post **156A**, abut surfaces on opposite sides of wax-up framework **150**. In the preferred embodiment, post portion **1000** of alignment post **156A** extends into aperture **158** in fittings **152A**, and is threadedly engaged to post portion **1002** of alignment post **156A** extending into aperture **158** from the other side of the wax-up framework **150**. Pin portion **1000** has external threads that are coupled to and engage mating internal threads of pin portion **1002**.

Fitting **152A** (FIG. **15**), has several surfaces that engage alignment post **156A**. These include frusto-conical sections **160**, **162**, **164** as well as cylindrical sections **166**, **168**. Frusto-conical sections **160**, **162** engage matching frusto-conical portions **161**, **163** of the shank of post portion **1002**. Frusto-conical section **164** engages a matching frusto-conical section **165** of the shank of post portion **1000**. Tightening post portions **1000**, **1002** by threading one into the other through

aperture **158** causes the compressive forces exerted on the frusto-conical and cylindrical sections **160**, **162**, **164**, **166** and **168** to align the longitudinal axes of post portions **1000**, **1002** coaxial with each other and coaxial with the longitudinal axis of fitting **152A** to which they are attached.

When tightened, the relative position of alignment post **156A** indicates the location in three dimensions of the mating surfaces of fitting **152A** and the angular alignment of those mating surfaces in three dimensions. They indicate the position and longitudinal axis of fittings **152A**. Post **156A** self-aligns with respect to fitting **152A** in a predetermined relative orientation when post **156A** is tightened on fitting **152A**.

For convenience and economy of illustration, only fitting **152A** and alignment post **156A** are illustrated herein. Since fittings **152A** and **152B** are identical to each other, and since alignment posts **156A** and **156B** are identical to each other, the description above of fitting **152A** and its alignment post **156A** applies equally to fitting **152B** and its alignment post **156B**.

There are four other fittings **152** comprising wax-up framework **150**. They are identified as fittings **152C**, **152D**, **152E**, and **152F**. These fittings are identical as are their corresponding alignment posts **156C**, **156D**, **156E**, and **156F**.

For convenience and economy of illustration, only fitting **152C** is shown in axial cross section in FIG. **16**, coupled to its associated alignment post **156C**. It should be understood that the other fittings and their corresponding alignment posts are identically configured and arranged and that the description below of fitting **152C** and alignment post **156C** applies equally to fittings **152D**, **152E**, **152F** and alignment posts **156D**, **156E**, **156F**.

Fitting **152C** differs from fitting **152A** in that it has no aperture **158** extending through the fitting. Instead, fitting **152C** is generally cylindrical having a cylindrical or frusto-conical recess **159** with a generally flat bottom.

Recess **159** has two frusto-conical surface portions **172**, **174** that engage mating frusto-conical surface portions **173**, **175**, respectively, on alignment post **156C**. Surface portions **172**, **174** are the surfaces that, when duplicated in the metal framework, mate with mating surfaces **108** of anchors **104** (or an intermediary component attached to anchor **104**). These mating pairs of frusto-conical surface portions on the alignment post and on the fitting orient the alignment post with respect to the fitting such that the longitudinal axis of the fitting and the alignment post are the same. The position and orientation of alignment post **156C** therefore indicates the position and longitudinal axis of fitting **152C**. Since post **156C** is fixed directly to fitting **152C**, it represents the position and orientation of fitting **152C**, and not the position and orientation of the bridging structure **154** that is fixed to and surrounds fitting **152C**. Alignment post **156C** is held in place in fitting **152C** by frictional or snap engagement of an inwardly facing and flexible lip **170** that captures a flange extending outward from the periphery of alignment post **156C**. This mechanical inter-engagement prevents post **156C** from being withdrawn from fitting **152C** without significant mechanical force being applied, however this mechanical engagement could be replaced by a screw retainment mechanism. It also holds post **156C** in its proper and predefined (preferably coaxial) orientation with respect to fitting **152C**. Post **156C** is configured to self-aligns with fitting **152C** in a predetermined relative orientation when it is attached. Fitting **152C** is configured to hold post **156C** in a specific alignment with respect to the fitting when assembled.

FIG. **17** illustrates alignment post **156A** in greater detail as it is aligned when tightened with fitting **152A** (shown in phantom lines). As shown in FIG. **17**, both of post portions

1000, 1002 of alignment post 156A are threaded together in a coaxial relationship as are when engaged and aligned to fitting 152A. Each of post portions 1000, 1002 is in the form of an elongated body having a predefined surface geometry (here shown as spherical outer surface portions 176) at one end of the post portion 1000, 1002 and the frusto-conical surfaces 161, 163, 165 disposed at the other end.

The spherical outer surface portions 176 on each of the alignment post portions 1000, 1002 of alignment post 156A (FIG. 17) are configured to have centers disposed on the longitudinal axes of each of the alignment post portions 1000, 1002 and are also concentric with the longitudinal axis of fitting 152A. The threads on alignment post portions 1000, 1002 are concentric as well. Furthermore, the cylindrical and frusto-conical surfaces on each alignment post portion are symmetric surfaces of revolution about the common longitudinal axis. Alternatively, other alignment posts with concentric geometrical shapes or even known irregular shapes can be used to identify the position and orientation of the fittings 152A.

As a result of this arrangement, when alignment post portions 1000, 1002 are threadedly attached to each other through aperture 158 in fitting 152A, the center points of each of the spherical outer surface portions 176 are disposed on the longitudinal axis of fitting 152A in which they are mounted. Furthermore, portions 176 are located at a predetermined distance apart from each other, and at a predetermined distance from the mating surfaces of the fitting 152A.

FIG. 18 illustrates alignment post 156C. This alignment post includes two spherical surface portions 178, 180. Spherical portion 178 is disposed at one end of the elongate alignment post 156C, and the two frusto-conical portions 173, 175 are disposed at the other end. Second spherical portion 180 is spaced apart from spherical portion 178, disposed partway between the two ends of post 156C. Both spherical surface portions 178, 180 have centers that are disposed on the longitudinal axis of post 156C. Frusto-conical surfaces 173, 175 are both symmetric surfaces of revolution about the longitudinal axis of post 156C. Alternatively, other alignment posts with concentric geometrical shapes or even known irregular shapes can be used to identify the position and orientation of the fittings 152C.

Referring now to FIG. 19, a scanner 182 including a scanning unit 184 having a chassis 185 and a laser probe 187, a digital microprocessor-based computer 186, a display screen 188, a keyboard 190, and a digitizer 192 are illustrated, together with wax-up framework/alignment post assembly 196 (see also FIG. 14) which is coupled to and supported on scanning unit 184 by a jig 194 mounted on chassis 185. Preferably a NEXTEC WizProbe.

Computer 186 is configured to control the scanning process and to interact with each of the other components, including the scanning unit, display screen, keyboard, and digitizer. Computer 186 includes a program that is configured to scan the surface of the framework/alignment post assembly 196 (comprising wax-up framework 150 and alignment posts 156) and to store coordinates of each point it scans on the surface of assembly 196 in its internal memory. The coordinates stored for each point are three-dimensional coordinates, sufficient to represent the position of each point in three dimensions. These positions may be absolute, or they may be relative with respect to a known position.

Scanning unit 184 is configured to scan assembly 196 under the control of computer 186 to which it is coupled. Scanning unit 184 preferably includes programmable mechanical positioning stages configured to change the relative position of the laser probe 187 with respect to the assem-

bly 196 thus permitting scanner 182 to gather position data from the surface of assembly 196 from all sides. In addition, jig 194 may include mechanical positioning stages from which it can change the relative position of assembly 196 in relation to the laser probe 187.

The operator interacts with scanner 182 using display screen 188, keyboard 190, and digitizer 192 which are coupled to computer 186. Using keyboard 190 and digitizer 192 (preferably a mouse or digitizer pad), the operator enters commands that direct scanner 182 to perform the operations described herein. Display screen 188 is coupled to computer 186 to permit the operator to view the collected scanned surface point coordinates (point clouds) in three dimensions, to select various points of the point clouds for mathematical manipulation, to remove particular points from the point cloud, and to instruct the scanner 182 how to scan assembly 196.

The process of manufacturing a dental framework from the wax-up framework 150, is shown in FIG. 20. The first steps of this process, described below, are the steps performed by the scanner 182 under the control of the scanner operator and computer 186. The computer instructions that configure the computer to perform these steps are stored in a digital memory of the computer 186.

In general, and as described below in greater detail, the process includes scanning the surface of the assembly 196 to determine the general overall shape of the wax-up framework 150. This shape, represented as a point cloud dataset, is a surface model of the wax-up framework in a preliminary form. This surface model is then further modified and refined by removing the points in the point cloud dataset representing the alignment pins and adding surface structures (typically in parameterized form and not as individual points) representing the surface of fittings 152 that will attach to anchors 104. This complete surface model is then used in subsequent manufacturing processes such as computer numeric controlled multi-axis machining, to create the framework for the denture.

In the first step of the framework manufacturing process, step 200, the computer 186 signals scanning unit 184 to scan the surface of assembly 196. Scanning unit 184 responsively scans the surface and transmits the coordinates of each point on the surface of the assembly 196 to computer 186. As necessary, computer 186 directs the scanning unit to reposition laser probe 187 with respect to assembly 196 in order to scan substantially the entire surface of assembly 196.

In the next step in the process, step 202, computer 186 derives the location of fitting surfaces from the predetermined geometry of the fittings 152 and the alignment posts 156. In the preferred embodiment, in order to determine the position of the mating surfaces of fittings 152 (and hence their position with respect to anchors 104 to which the final framework will be coupled), computer 186 is configured to use the geometry of the alignment posts 156 and the fittings 152 together with the coordinates of the point scanned on the surface of the alignment posts 156 to determine the precise location of the fitting 152 surfaces with greater accuracy than computer 186 could do if it scanned the fitting surfaces 152 surfaces directly.

Computer 186 is programmed to derive the center of each of the spherical surface portions 176, 178, 180 on each of the alignment posts from the coordinates of each point on spherical surface portions 176, 178, 180 that it previously stored. Each of the datum points in the point cloud dataset that were scanned from the surface of the alignment posts (including spherical surface portions 176, 178, 180) have an associated position error. Due to this error, directly scanning the cylindrical and frusto-conical surfaces of fittings 152 may not be sufficiently accurate to determine the orientation and position

of the mating surfaces of the fittings 152 to which anchors 104 are coupled (in the metal duplicate of wax-up framework 150). To reduce this error, alignment posts 156 are provided with the spherical surface portions 176, 178, 180 which have larger surface areas than the mating surfaces of fittings 152 to which they are coupled. These spherical surface portions 176, 178, 180 have known predetermined geometrical shapes and orientations with respect to the fittings 152. These shapes and orientations are programmed into computer 186, which employs algorithms incorporating this predetermined geometry to derive a more accurate position and orientation for the mating surfaces of fittings 152.

In particular, computer 186 is programmed with the diameter (or radius) of each of the spherical surfaces 176, 178, 180 as well as the distances between the centers of the spherical surfaces 176, 178, 180 and the fittings 152, as well as the particular shape and orientation of the frusto-conical and cylindrical surfaces of the fittings 152 themselves. Computer 186 is configured to fit the set of data points for each spherical surface 176, 178, 180 of alignment posts 156 to an ideal sphere having the same diameter (or radius). It is therefore configured with the geometric parameters (in this case the diameter) of geometric surfaces (spherical surface portions 176, 178, 180) on alignment posts 156 and applies these parameters to points gathered from a scan of the geometric surfaces to derive other geometric parameters (in this case the center of spherical surface portions 176, 178, 180). In the preferred embodiment, the technician uses the digitizer to select data points by selecting regions on the screen that show portions of the point cloud dataset having the predetermined geometry. Once selected, the technician signals the computer to calculate the parameters of a predetermined geometry that best fits the selected data points of the point cloud dataset. The computer 186, in turn sequentially fits a surface of the predetermined geometry to the selected data points until it determines the parameter of a geometry having a best fit to the data points. In the preferred example, the computer 186 fits the data points to a sequence of spheres having different diameters and center locations until it finds a diameter and center point of a sphere that fits the data points best. The computer 186 then saves the center point of this sphere for later use in determining the location of the surfaces of the fittings in the manner described below.

In a preferred embodiment, computer 186 is configured to find the center of the spherical surface portions by using an algorithm incorporating error minimizing mathematical methods. In the example given here, computer 186 is configured to calculate the root mean square (RMS) error of all the data points scanned from the spherical surface portions 176, 178, 180 (and selected by the technician) with respect to the closest data points on the surface of the ideal sphere and vary the diameter and center of the ideal sphere to minimize this error until computer 186 determines a center having the smallest RMS error. The results of this calculation are coordinates for the center of the sphere that is closest to the centers of the spherical surface portion.

Computer 186 is configured to repeat this process of fitting data points of a spherical surface portion to an ideal sphere having the same diameter for data points scanned from each spherical surface portion. In this manner, computer 186 derives the coordinates of the centers of each of the spherical surface portion 176, 178, 180 for all of the alignment posts 156.

In its digital memory, computer 186 stores the geometry of each of the alignment posts 156 and the position and orientation of alignment posts 156 with respect to fittings 152 when they are coupled together. In particular, computer 186 stores

the distance between the spherical surface portions 176, 178, 180 of the alignment posts 156 and the distances between these centers and the mating surfaces of fittings 152. Once computer 186 calculates the centers of spherical surface portions 176, 178, 180 using the method above, and since spherical surface portions 176, 178, 180 are aligned on the longitudinal axis of the alignment posts 156, computer 186 can easily calculate the location and orientation of fittings 152 linearly interpolating between the previously calculated centers of spherical surface portions 176, 178, 180. By combining this geometric distance information with the previously determined centers of each of the spherical surface portions, computer 186 can determine the precise location and angular orientation of fittings 152, particularly, the cylindrical and frusto-conical surfaces on the fitting 152 to which the posts 156 having those centers are fixed. It is these surfaces on fittings 152 (in the metal duplicate of wax/acrylic framework 150) to which mating surfaces 108 of anchors 104 are mounted.

In this manner, even though the mating surfaces of fittings 152 are hidden by the alignment posts 156 during scanning, computer 186 is able to determine their precise location and orientation using stored data indicating parameters of the predetermined geometric shapes (diameter/radius of the spherical surface portions 176, 178, 180, distance from the centers to the fittings 152, and shape of the mounting surfaces on the fittings, etc.) comprising alignment posts 156 and their predetermined relationship to fittings 152 when properly attached to the fittings. In this manner, a scanner can determine with much greater accuracy the shape, position, and orientation of surfaces that it could not determine directly by scanning those surfaces.

One reason this method is an improvement is due to the difference in surface area between the mating surfaces on fittings 152 as compared to the spherical surface portions 176, 178, 180 of alignment pins 156. The mating surfaces 160, 162, 164 on fittings 152 are relatively small and difficult to scan.

While it is possible to scan the mating surfaces of fittings 152 (e.g. the surfaces to which anchors 104 will be fixed), nonetheless due to their small size any position measurements taken using current technology would not give the accuracy of position and orientation required to insure a precise fit between the denture and the anchors. The supplemental or extension surfaces on the alignment posts 156 (e.g. spherical surface portions 176, 178, 180) are much larger and thus can be scanned to generate many more data points (i.e. data scanned on the spherical surface portions 176, 178, 180) that, combined with knowledge of supplemental surfaces geometry, provides more data points and permits a more accurate determination of the location of fittings 152 thereby effectively increasing the accuracy of the derived datum point, in particular the radius (or diameter) and the center point of the spherical surface portion.

At this step in the process, computer 186 has determined the longitudinal axes of each of the alignment pins 156 and hence the longitudinal axes of each of fittings 152. Computer 186 has also determined the location along each of the longitudinal axes where the fitting 152 associated with the axis is located. This calculated axial orientation and position information comprise a vector that defines the location and angular orientation of the mating surfaces of each fitting 152.

In the next step of the process, step 204 (FIG. 20), computer 186 is configured to remove the alignment posts 156 from the set of surface data points of the assembly 196—i.e. the point cloud dataset created from the coordinate data scanned from

the surface of assembly **196** by scanner **182**. The reduced dataset produced by the operation is shown schematically in FIG. **21**.

In FIG. **21** the point cloud dataset **205** (i.e. the preliminary surface model of the wax-up framework **150**) is shown with alignment posts **156** removed and replaced symbolically with vectors **198** and circle center points **199**. The eight vectors **198** represent the longitudinal axes of alignment pins **156** and fittings **152**. The circle centers **199** represent the centers of the spherical surface portions **176**, **178**, **180** of alignment pins **156** derived as described above. The data points scanned from the surface of the alignment pins **156** are not shown in FIG. **21**, but have been removed by computer **186**.

In the next step of the process, step **206**, computer **186** further modifies the surface model **205** of the framework by combining the remaining portion of the point cloud dataset (i.e. with the alignment pins removed) with a surface model of flat surfaces or pads **207** defining an exposed surface of each fitting **152**. These parameterized flat surfaces or pads are stored in a digital electronic memory of the computer **186**. This process is preferably done by Boolean union.

These flat surfaces or pads represent the surface of the fittings that face the patient's mucosal tissue. Computer **186** previously determined the orientation and location of each of the fittings **152** (and thus pads **207**) based upon the computer's calculation of the center points of the spherical surface portions of posts **156**. Computer **186** also stores a parametric representation of the shape, location and orientation of the surfaces of each fitting **152**. In the preferred embodiment, computer **186** stores numerical models of fittings that the user selects and inserts into the surface model of wax-up framework **150**. FIG. **22** shows the surface model **205** of FIG. **21** after computer **186** has modified it with the addition of pads **207**.

In the next step in the process, step **208** (FIG. **20**), computer **186** is configured to insert fitting surfaces—particularly the surfaces of the fittings that mate with mating surfaces **108** of anchors **104**. The computer **186** has determined the orientation and location of each fitting **152** (step **202**) to determine the location of the fitting. Digital parameterized fittings **152'** are digital models of the mating surfaces of actual fittings **152** that are configured to engage anchors **104** or surmounted abutments. These digital parameterized fittings are stored in a digital electronic memory of the computer **186**. In the preferred embodiment, the computer **186** performs a Boolean subtraction thereby combining the appropriate selected digital parameterized fittings **152'** with the surface model **205** to insert the mating surfaces of the fitting into the surface model. In the illustrated embodiment this removes portions of the surface model **205** underneath the surface of pads **207** to the appropriate depth, leaving the sunken mounting surfaces surrounded by a surrounding portion of pads **207**. The surface model **205** as it exists before the Boolean subtraction is shown in FIG. **22**. The surface model **205** after the Boolean subtraction and insertion of the mounting surfaces of fittings **152'** is shown in FIG. **23**.

In the next step of the process, step **210**, computer **186** calculates the tool paths for manufacturing the actual dental framework from the surface model **205**. There are a variety of processes by which the actual denture framework can be manufactured and hence a variety of tool paths that can be generated. For example, the calculated tool paths can describe the path of a single or multi-axis CNC cutting tool such as a multi-axis milling machine, the path of an EDM electrode, or the path of a material deposition device such as stereolithography, rapid prototyping, 3D printing, or laser sintering machines. Even further, the tool path may comprise several

tool paths for different machines and processes that are performed in succession to manufacture the denture framework from surface model **205**. Even further, the tool path can define the path of a tool used to manufacture a mold in which the denture framework (or a precursor thereto) is cast.

In the final step in the process, step **212**, the tool path is used to manufacture the denture framework. Typically the tool path is loaded in digital form into a computer numeric controlled (CNC) machine that drives a tool such as a material removal tool to remove excess material or a material deposition tool to build up material. The framework may be machined in a single process or in a series of processes on several machines. In the preferred embodiment, the denture framework is preferably manufactured by a multi-axis computer numeric controlled (CNC) milling machine. In an alternative process, the bridging structures **154** of the framework **150** are manufactured from the surface model **205** using one process, such as a milling machine, and recessed portions, such as the mounting (mating) surfaces of the fittings **152**, are manufactured using another process, such as wire electrodischarge machining (EDM) or plunge EDM. In another alternative process, the milling machine, stereolithography, rapid prototyping, 3D printing, or laser sintering machines or EDM can be used to manufacture the mold in which the denture framework (or a precursor thereto) is cast.

The framework is preferably manufactured from titanium, zirconia, alumina, or other ceramic material having mechanical strength characteristics similar to titanium. If it is a ceramic material, the material can be machined in its fully sintered state or in a partially green or fully green state in which the ceramic material is only partially sintered, or has not been sintered at all. A ceramic (e.g. zirconia) may be cast in a mold that has been machined using the surface model and then sintered to form the final part. Alternatively, the ceramic may be cast in a mold that only approximates the shape of the final framework indicated by the surface model and then subsequently machined to the final dimensions using machining tools employing tool paths generated from the surface model.

Once the final framework has been made, it is returned to the dentist together with the stone cast **125** and the wax-up framework **150**. The dentist then verifies the accurate manufacture of the final framework and then follows his traditional procedures in manufacturing a denture from the final framework.

One of the reasons this process above is recommended is because of the unfamiliarity of dentists with the technology and the need to, at least initially, permit them to have the greatest degree of control in the denture manufacturing process. As they become more comfortable with the process, however, the dentist can dispense with additional dentist-performed steps, such as the creation of the stone cast, the putty index, and the wax-up framework can be dispensed with by scanning the dentist's handiwork earlier in the process. This is beneficial because it reduces the possibility of error and inaccuracies by eliminating several of the replication steps. In the process proposed above, the dentist would first make a negative replica of the mandible (or the maxilla) with an impression. The dentist would then use the impression to make a positive replica of the mandible (or the maxilla) with a stone cast. The dentist then uses the stone cast to define the mating surface locations of the framework, and then the wax-up framework itself is scanned. Each of these transfer steps generates a small amount of error, which can be eliminated once dentists are comfortable with the accuracy of the final framework that is manufactured using the scanning technology.

In a first alternative process for manufacturing the final framework, the dentist will manufacture the stone cast **125** as described above, but will not manufacture the framework, leaving the design and manufacture of the framework to the laboratory. This first alternative process is shown in FIG. **24**.

The first steps of this alternative process are performed exactly as they are in the process described above: the dentist places anchors in the patient's mouth, waits for them to heal, takes an impression of the patient's mouth, and makes a stone cast from that impression. Once the stone cast has been created, however, the dentist does not manufacture the wax-up framework. Instead, the dentist sends the stone cast directly to the laboratory and the laboratory scans the stone cast, then designs and manufactures the final framework from the stone cast. In the discussion of this process below, the stone cast is referred to as stone cast **125** since it is made in exactly the same manner as the stone cast **125** in the example above: it is configured to receive a framework having six fittings that include two fittings **152A**, **152B** with through holes and four fittings **152C**, **152D**, **152E**, **152F** without through holes.

This first alternative process is shown in FIG. **24**. In step **214** of the first alternative process, the dentist sends the stone cast **125** to the laboratory. The dentist may also send a diagnostic wax-up **130** or putty index **142** of the denture.

In step **216**, the laboratory inserts six alignment posts **156** into the analogs **124** embedded in the stone cast **125**. These alignment posts **156** are the same as the alignment posts shown in FIGS. **14-18** with one difference: their mating surfaces are configured to engage the mating surfaces of analogs **124** and hold the alignment posts coaxial with the longitudinal axis of analogs **124**. They may have differently shaped flat, frusto-conical and cylindrical surfaces configured to engage with the mating surfaces of analogs **124** instead of the fittings **152**. As in the case of alignment posts **156** described above in the first process, the alignment posts **156** used in this first alternative process have two spherical surfaces comprising centers coaxial with coping **110**. Since they are mounted to analogs **124** on the stone cast, all six of the alignment posts **156** mounted on stone cast **125** are of the style identified above as **156C-F**, comprising a single post portion having two spherical surface portions. As in the first process described above, these fittings need not have a spherical surface portions, but may have any predetermined geometric shape. Further, and as described above, the alignment posts **156** can be dispensed with in this step of the first alternative process and the analog surfaces can be scanned directly by scanner **182** if scanner **182** is of sufficient accuracy that it can scan and determine the position and orientation of the mounting surfaces of analogs **124** without the need of attaching a supplemental surface to those mounting surfaces, such as the alignment posts **156**.

The shape and orientation of the mounting surfaces on the alignment posts **156** in this alternative process are not configured to engage mating surfaces on fittings **152** in the wax-up framework **150**, but are configured to engage with exposed mating surfaces on the analogs **124** in the stone cast **125**. As in the case of the alignment posts **156** attached to fittings **152**, the mating surfaces on the alignment posts and the mating surfaces on the analogs **124** interengage to cause the alignment posts **156** to be aligned coaxial with analogs **124**. The alignment posts **156** cover the free ends of the analogs **124**.

In step **218**, once the alignment posts **156** have been attached to the analogs **124**, the scanner **182** is configured to scan the alignment posts and the soft tissue replica of the patient's mouth formed in the surface of the stone cast **125**, and the alignment posts **156**. This scanning is done in the same manner as described above in conjunction with FIG. **20**.

The surfaces of stone cast **125** that are scanned by scanner **182** include the surfaces of the stone cast that replicate the mucosal tissue in the patient's mouth. Scanner **182** stores in the memory of computer **186** a first point cloud dataset of the stone cast **125** with alignment posts **156** attached. In step **218**, scanner **182** also scans the surface of diagnostic wax-up **130** and the surface of stone cast **125** (preferably when they are assembled) and saves a second point cloud dataset collectively representing the scanned surface of the diagnostic wax-up **130** and stone cast **125**. Alternatively, the operator can scan the diagnostic wax-up **130** separately from the stone cast and later register the point cloud dataset of the stone cast **125** and the diagnostic wax-up **130**. As a further alternative, instead of scanning the diagnostic wax-up **130** scanner **182** can scan the putty index **142**.

When the diagnostic wax-up **130** is scanned, it can be scanned either in its proper position on the stone cast **125**, or it can be scanned separately.

If it is scanned on the stone cast **125**, the scan preferably includes data points taken from all the exposed external surfaces of the diagnostic wax-up **130** (i.e. the outwardly facing surfaces that model the gum and the teeth) as well as surfaces of the stone cast **125** adjacent to the diagnostic wax-up **130**. The surfaces of the stone cast **125** adjacent to the diagnostic wax-up that are scanned in the second point cloud dataset are also preferably scanned in the first point cloud dataset and thus there is some overlap in surface contours in both the first and the second point cloud datasets—both datasets include data points scanned from the same surfaces of stone cast **125**. This permits later registration of the first and second point cloud datasets.

If the diagnostic wax-up **130** is scanned when it is separate from the stone cast **125**, it is preferably scanned so that the second point cloud dataset includes data points taken from all the exposed external surfaces of the diagnostic wax-up **130** (i.e. the outwardly facing surfaces that model the gum and the teeth) as well as surfaces of the diagnostic wax-up **130** that would abut stone cast **125** if the diagnostic wax-up **130** was mounted on the stone cast. Since the diagnostic wax-up **130** was formed by molding a plastic material to the surface of the stone cast **125**, the scanned surface contour of the diagnostic wax-up **130** that abut the stone cast are a mirror image of surface contours of the stone cast **125**.

In the preferred embodiment these abutting stone cast **125** surfaces were scanned previously and are a part of the first point cloud dataset. Thus, the first and second point cloud datasets include a subset of data points taken from mirror image surface contours—surface contours common to both the first and second point cloud datasets—common to the diagnostic wax-up **130** and to the stone cast **125**. This permits later registration of the first and second point cloud datasets.

In a further alternative, the putty index **142** may be scanned instead of the diagnostic wax-up **130**. When the putty index **142** is scanned, it can be scanned either in its proper position on the stone cast **125**, or it can be scanned separately.

If the putty index **142** is scanned while on the stone cast **125**, the scan preferably includes data points taken from all the exposed external surfaces of the putty index **142** (i.e. the inwardly facing surfaces of the putty index that were molded to the outwardly facing surfaces of the diagnostic wax-up **130** (i.e. the facial aspect, including the outwardly facing teeth **132** and gum **134** of the diagnostic wax-up **130**) as well as surfaces of the stone cast **125** adjacent to the putty index **142** when it is fitted on the stone cast **125**. The surfaces of the stone cast **125** adjacent to the putty index **142** that are scanned in the second point cloud dataset are also preferably scanned in the first point cloud dataset and thus there is some overlap in

surface contours in both the first and the second point cloud datasets—both datasets include data points scanned from the same surfaces of stone cast **125**. This permits later registration of the first and second point cloud datasets.

If the putty index **142** is scanned when it is separate from the stone cast **125**, it is preferably scanned so that the second point cloud dataset includes data points taken from all the exposed external surfaces of the diagnostic wax-up **130** (i.e. the outwardly facing surfaces that model the gum and the teeth) as well as surfaces of the putty index **142** that abut stone cast **125** when the putty index **142** is mounted on the stone cast. Since the putty index **142** was formed by molding a plastic material to the surface of the stone cast **125** and to the facial aspect of the diagnostic wax-up **130**, the scanned surface contour of the putty index **142** that abut the stone cast are a mirror image of surface contours of the stone cast **125**.

In the preferred embodiment, these abutting stone cast **125** surfaces were scanned previously and are a part of the first point cloud dataset. Thus, the first and second point cloud datasets include a subset of data points taken from mirror image surface contours—surface contours common to both the first and second point cloud datasets—common to the putty index **142** and to the stone cast **125**. This permits later registration of the first and second point cloud datasets.

In step **220**, computer **186** is configured to derive the location and orientation of the mating surfaces of the analogs from the predetermined geometry of the alignment posts **156**, in the same manner as it determined the location and orientation of the mating surfaces of the fittings in step **202** (FIG. **20**).

In step **222**, computer **186** is configured to remove the data points corresponding to the alignment posts from the first point cloud dataset in the same manner as it removed the alignment posts in step **204**.

In step **224**, computer **186** is configured to generate a first surface model of the stone cast **125** from the first point cloud dataset. This surface model includes the analogs as they would appear uncovered, with alignment posts **156** removed, and the surface of stone cast **125** that replicates the patient's mucosal tissue. The first surface model includes the mating surfaces of the analogs **110**, which represent the anchors **104** in the patient's mouth. Further in step **224**, computer **186** generates a second surface model of diagnostic wax-up **130** (or alternatively putty index **142**) from the second point cloud dataset.

The first surface model and the second surface model include surface contours that are common to both the first and second point cloud datasets: they include data points in each model that were scanned from a common surface, preferably a portion of stone cast **125** that was scanned into both the first and the second point cloud datasets, or they include data points of abutting surfaces in the first and second point cloud datasets.

In step **226**, computer **186** is configured to generate a surface model of a dental framework **228** (FIGS. **25-27**) from the first surface model of the stone cast **125** that was generated in step **224**. Computer **186** is first configured to generate the fittings in the final framework that mate with mating surfaces **108** of anchors **104**. The computer **186** refers to an internal library of digital parameterized fittings **152"** which define in parametric form the location and orientation of the mounting surfaces of the actual fittings. The digital parameterized fittings **152"** are digital models of the surfaces of the actual fittings that are configured to engage anchors **104**. These digital parameterized fittings can be pre-designed, modified by the user, derived from existing alignment post

CAD geometries, or free form designed. These digital parameterized fittings **152"** are stored in a digital electronic memory of the computer **186**.

Computer **186** electronically stored at least one and preferably a plurality of different digital parameterized fittings **152"** (shown in FIGS. **25, 26, 27** as items **152"A, 152"B, 152"C, 152"D, 152"E, and 152"F**) in its internal library between which it can select. These digital parameterized fitting **152"** have surfaces that are configured to mate with the analog **124** surfaces in the first surface model of the stone cast **125** that were derived in step **220**.

In step **220**, above, computer **186** determined the location and orientation of the six analogs **124** in the stone cast **125** in the first point cloud dataset of the first alternative process. Computer **186** sequentially selects a digital parameterized fitting **152"** from its internal library for each of the analogs and aligns the mating surface (or surfaces) and axis of the selected digital parameterized fitting **152"** with the surface (or surfaces) and axis of one of the analogs whose location and orientation it determined in step **220**. Computer **186** repeats this process for each of the six analogs **124** whose location and orientation were determined in step **220**, until it has built up a surface model of dental framework **228** comprising the six digital parameterized fittings **152"** (shown in FIGS. **25-27** as items **152"A, 152"B, 152"C, 152"D, 152"E and 152"F**).

As in the case of the digital parameterized fittings **152'** in FIG. **20**, these fittings are configured to engage mating surfaces **108** of anchors **104**. The digital parameterized fittings **152"** mathematically represent the structures that will be coupled to the anchors **104** in the final denture framework that is mounted in the patient's mouth.

Further in step **226**, the computer **186** is configured to generate a surface model of bridging structure **154'** (FIGS. **25-27**) that will join the six digital parameterized fittings **152"**. This includes the computer **186** determining the cross-sectional shape, length and location of the bridging structures as described below. This surface model of this bridging structure **154'** extends between and joins the six digital parameterized fittings **152"** and thereby completes the surface model of the dental framework **228**. Bridging structure **154'** also comprises the portions **155** that extend away from the end digital parameterized fittings **152"A and 152"B** and are supported only at one end. One form of the bridging structure is shown in FIGS. **25-27** as a simple elongated member having a predetermined cross section. Other forms that computer **186** is configured to calculate include

To generate bridging structure **154'**, computer **186** determines the shape, length, and location of the individual portions of the bridging structure between each of adjacent digital parameterized fittings **152"**. It is further configured to determine the shape length and location such that the individual portions will not intersect the first surface model (i.e. the surface model of the stone cast **125** provided in step **222**). Since the surface of the stone cast represents the exposed surfaces (including mucosal tissue) in the patient's mouth, this reduces the likelihood that the physical framework created from the surface model will contact and damage the patient's mucosal tissue. Computer **186** is configured to provide a separation distance between the surface model of the stone cast and the bridging structures. In one arrangement the computer **186** is configured to place the bridging structures a predetermined minimum distance from the surface model of the stone cast. In another arrangement the computer is configured to permit the operator to select a desired minimum distance between the bridging structure and the surface model of the stone cast. In another arrangement, the computer is configured to offer to and/or accept from the operator only a

certain range or number of minimum separation distances, such minimum separation distances preferably ranging between 1 mm and 5 mm.

Computer **186** is configured to create the bridging structure extending from or between each of the digital parameterized fittings by providing a pre-designed list of bridging structure forms (e.g., pontic form, abutment/tooth form, bar form wherein the bar form is e.g. a cylinder, circle, ellipse, square, polygon or other geometric shape) that have been previously stored in the electronic memory of the computer. In one configuration, the computer is configured to automatically select the cross sectional dimensions of each form (diameter, radius, major and minor diameter, height, width, etc.). In another configuration the computer is configured to present the user with a list of pre-set values or defined by the user among which the user can select preferred dimensions. In yet another configuration, the computer is configured to prompt the user to enter specific numeric values for these dimensions. The form of the bridging structures can also be defined by the user.

Computer **186** is configured to determine the proper location of the bridging structure **154'** extending from each of the digital parameterized fittings **152"** by locating the beginning and end of each structure according to position information for the fitting that is derived from the scanned point cloud dataset.

In another arrangement, the computer **186** is configured to determine the location of the bridging structure **154'** extending from each of the digital parameterized fittings **152"** by locating the beginning and end of each structure according to reference points and axes assigned to the digital parameterized fittings **152"** by the computer program from a list of pre-set values or defined by the user. For example, each digital parameterized fitting which is placed in the model may have only certain types of bridging structures to which it can be connected, and may only connect to those bridging structures at certain locations one the digital parameterized fitting. This information is stored in the electronic memory of computer **186** in association with each digital parameterized fitting. When a particular fitting is inserted into the model, computer **186** is configured to the type and location information associated with the inserted fitting and locate (or permit the operator to locate) bridging structures of the type and at the locations compatible with those digital parameterized fittings. In another arrangement computer **186** is configured to locate the bridging structure **154'** (e.g., pontic form, abutment/tooth form, bar form) between each of the digital parameterized fittings **152"** by locating the beginning and end of each structure according to free form features selected by the user between each of the digital parameterized fittings **152"**.

In the case of distal extensions **155**, computer **186** is configured to cantilever them off the digital parameterized fittings **152"** and extend them distally along the arch of the patient's mouth. These distal extensions **155** are preferably 20 mm in overall length or less. They are also selected as described above.

Computer **186** is configured to conduct a mechanical design analysis of the distal extensions **155** that validates shear and bending strength limits for those geometries relative to their chosen material and shapes. Computer **186** is configured to apply the appropriate shear, tensile and compressive stress analysis techniques to the chosen geometries automatically or from a pre-determined list of tests chosen by the user. Upon successful analysis of the distal extension designs, the extensions are verified or accepted by the user.

As part of the step of generating the bridging structure **154'** computer **186** is configured to determine a location for the

bridging structure **154'** that will not intersect the second surface model (i.e. the surface model of diagnostic wax-up **130**). This insures that the bridging structure **154'** of the final denture framework will not stick through, but will be disposed within, the body of the denture. Computer **186** first aligns or registers the first point cloud dataset (representing the stone cast **125** surfaces) with respect to the second point cloud dataset (representing the diagnostic wax-up **130** surfaces), thereby mathematically determining the three-dimensional volume defined by the diagnostic wax-up **130**. This volume defined by the intersection of these two datasets is the volume of the denture as the dentist has designed it.

To align or register these two volumes, computer **186** is configured to identify the overlapping portions common to both the first and second point cloud datasets, i.e. the portions of both datasets that have the same (i.e. matching) surface contours. A preferred program for performing these functions is Raindrop Geomagic Studio Suite (by Geomagic of Research Triangle Park, N.C., USA).

In the first instance, the stone cast **125** is scanned to generate the first point cloud dataset, and the diagnostic wax-up **130** is mounted on the stone cast **125** and both are scanned to create the second point cloud dataset. The overlapping portions of the two point cloud datasets comprise the data points of the stone cast **125** for surfaces of the stone cast **125** that were scanned in both the first point cloud dataset and the second point cloud dataset.

In the second instance, the stone cast **125** is scanned to generate the first point cloud dataset and the diagnostic wax-up **130** is not mounted on the stone cast **125** but is scanned separately to create the second point cloud dataset. The overlapping portions of the two point cloud datasets comprise the surface of the stone cast **125** that abuts the diagnostic wax-up **130** in the first point cloud dataset, and the surface of the diagnostic wax-up **130** that abuts stone cast **125** when it is mounted on the stone cast **125** in the second point cloud dataset. Since the two abutting portions were formed by pressing the diagnostic wax-up **130** material against the stone cast when soft, the two abutting surfaces have identical surface contours that can be matched one to the other, and in that sense overlap.

In the third instance, the stone cast **125** is scanned to generate the first point cloud dataset, and the putty index **142** is mounted on the stone cast **125** and both are scanned to create the second point cloud dataset. The overlapping portions of the two point cloud datasets comprise the data points of the stone cast **125** for surfaces of the stone cast **125** that were scanned in both the first point cloud dataset and the second point cloud dataset.

In the fourth instance, the stone cast **125** is scanned to generate the first point cloud dataset and the putty index **142** is not mounted on the stone cast **125** but is scanned separately to create the second point cloud dataset. The overlapping portions of the two point cloud datasets comprise the surface of the stone cast **125** that abuts the putty index **142** in the first point cloud dataset, and the surface of the putty index **142** that abuts stone cast **125** when it is mounted on the stone cast **125** in the second point cloud dataset. Since the two abutting portions of the stone cast **125** and the putty index **142** were formed by pressing the putty index **142** material against the stone cast **125** when soft, the two abutting surfaces have identical surface contours that can be matched one to the other, and in that sense overlap.

In the third and fourth instances (that use the putty index **142**), the computer **186** locates the bridging structure **154'** by locating the bridging structure behind the portion of the second point cloud dataset that was scanned from the inner

surface of the putty index **142** that was formed by pressing it against the facial aspect of the diagnostic wax-up **130**. This portion of the second point cloud dataset in the third and fourth instance has the same surface contours as the facial aspect of the diagnostic wax-up **130**, which is a replica of the front of the body of the denture when made.

By locating the bridging structure **154'** behind the inner surface of the putty index **142** in the second point cloud dataset, the computer insures that the surface model of the denture framework thus created will not protrude through the front of the denture body.

By locating the bridging structure **154'** above the surface of the first point cloud dataset (i.e. stone cast **125**) that represents the surface of the mucosal tissue the computer **186** insures that the surface model of the denture framework **228** thus created will not extend through the lower surface of the denture body and abut the mucosal tissues of the patient.

Computer **186** digitally assembles each of the short bridging sections of the bridging structure **154'** and the digital parameterized fittings **152"** into the surface model of denture framework **228**. Computer **186** thereby generates the locations of the digital parameterized fittings **152"**, and the location of the bridging structures **154'** coupling the digital parameterized fittings **152"**.

A graphic example of the surface model of the denture framework **228** generated by the computer in this manner can be seen in FIGS. **25-27**, which illustrate a bottom view, front perspective view, and top view, respectively, of the surface model of the denture framework **228** and showing the digital parameterized fittings **152"** and bridging structure **154'**.

In the illustrated embodiment, each section of bridging structure **154'** has a constant cross-sectional area (in this case a circular cross section) designed to minimize manufacturing time of the final framework. In an alternative embodiment, computer **186**, when placing the bridging structure **154'**, is configured to customize the joints between the digital parameterized fittings **152"** and the sections of bridging structure **154'** by providing stress reduction factors such as radiused intersections between the digital parameterized fittings **152"** and bridging structure **154'**.

In the final step of this alternative process, step **230**, the framework is manufactured in the same manner as described above in accordance with step **212**.

Above were described two processes for manufacturing a dental framework. In the first process an impression **123**, then a stone cast **125**, then a wax-up framework **150** was made before anything was scanned. In the first alternative process an impression **123** and then a stone cast **125** was made before anything was scanned. This second process eliminated the need for creating a wax-up framework **150** and used a computer to generate the framework from an internal stored library of digital parameterized fittings **152"**. By eliminating additional replication steps, the possibility for error as well as the cost and time of manufacture is further reduced.

In a second alternative process for manufacturing a denture framework, the step of creating a stone cast **125** is eliminated and the impression **123** is used as the stone cast **125** was used in the first alternative process of FIGS. **24-27**. The dentist may, of course, make a stone cast **125** on which to create his diagnostic wax-up **130**, but the stone cast **125** in this second alternative process is not required for making a denture framework.

In the second alternative process, the dentist makes impression **123** as described in the first process and first alternative process (above) and sends it to the laboratory. The laboratory then mounts alignment posts **156** to the copings **110** located in the impression **123**.

Scanner **182** is configured to scan the interior surface of the impression **123**, which is a negative replica of the patient's mucosal tissues. This scan produces a first point cloud dataset that indicates the surface contours of the patient's mandibular mucosal tissues. The alignment posts **156** are coupled to the mating surfaces of the copings **110** embedded in the impression material.

The surfaces to which the alignment posts **156** are coupled are the surfaces that previously mated to the surfaces **108** of anchors **104**. This second alternative process is substantially the same as the first alternative process. The dentist can optionally send a diagnostic wax-up **130** of the desired denture as well.

In the second alternative process, alignment posts **156** are attached to copings **110** embedded in impression **123**. The impression **123** is a negative replica of the patient's mandible. The impression-plus-alignment-posts assembly is then fixed to jig **194**.

Scanner **182** then scans the inside surface of impression **123** formed by the patient's mandible, which includes the patient's mucosal tissue and any existing dentition and edentulous areas. Scanner **182** also scans the surface of the alignment posts **156**, which in this case are attached to the copings **110**. The alignment posts are preferably as shown in FIG. **18**, however the frusto-conical portions **173** and **175** may be configured differently to be fixed to the coping in a coaxial relationship in the same manner described above for the first process and the first alternative process.

Computer **186** is configured to save the three-dimensional data points of the interior surface of the impression formed by the patient's mandible and the alignment posts **156** as a point cloud dataset, to derive the location of the surfaces of copings **110** from the predetermine geometry, to remove the alignment posts **156** from the point cloud dataset of the impression-plus-alignment-posts assembly, to generate a surface model of the patient's mucosal tissue and the copings **110**, and to generate a surface model of a dental framework **228** in the same manner described above in conjunction with the first alternative process.

In the final step of the second alternative process, the surface model of the framework **228** is manufactured as in step **212**.

In a third alternative process, the surface model of a dental framework **228** can be generated from the diagnostic wax-up **130** itself.

In this process, shown in FIGS. **28-29**, the dentist first mounts fittings **152** on the analogs **124** embedded in the stone cast **125** in the same manner as described in the above processes.

In the next step, the dentist forms the diagnostic wax-up **130** on the stone cast **125**. The dentist molds the wax-up material to the surface of the stone cast **125** to capture the contours of the mucosal tissue as described above. The dentist also molds the wax-up material to the fittings **152**, embedding the fittings **152** in the wax-up material.

The completed diagnostic wax-up **130** supported on the stone cast **125** with the fittings **152** embedded in the diagnostic wax-up **130** are shown in FIG. **28**.

The dentist then removes the diagnostic wax-up **130** from the stone cast **125** and sends it to the laboratory.

Once at the laboratory, a technician fixes alignment posts **156** (preferably alignment posts **156C**, **D**, **E** or **F**, since they extend from only one side of the fitting **152** to which they are coupled) to the now-exposed mating surfaces of the fittings **152**. This arrangement is shown in FIG. **29**.

The technician then mounts the assembly of diagnostic wax-up **130** with alignment posts **156** to scanner **182** and

directs the scanner to scan the assembly in the same manner as described above for scanning wax-up framework 150 with alignment posts 156.

This scan produces a point cloud dataset representing the contours of the diagnostic wax-up 130 and the alignment posts 156.

As in the previous examples, the technician directs computer 186 to determine the location of the centers of the spherical surface portions of the point cloud dataset, and ultimately the location and orientation of the mating surfaces of the fittings 152.

Computer 186 then generates a surface model of a framework 228 that will be enclosed within the diagnostic wax-up 130. Computer 186 inserts digital parameterized fittings 152" into the surface model of a denture framework 228 that correspond to fittings 152. Computer 186 then inserts the bridging structure 154' and distal extensions 155 into the surface model of a denture framework 228.

To generate bridging structure 154', computer 186 determines the shortest distance between each of the adjacent digital parameterized fittings 152" that will not intersect the surface model of the diagnostic wax-up 130, but will be contained completely within the contours of the diagnostic wax-up 130. Computer 186 already has the surface contours of the diagnostic wax-up 130 because it already scanned the surface of the diagnostic wax-up 130 in the point cloud dataset. This insures that the actual bridging structure of the denture framework (created from the model of the bridging structure 154') will not protrude through, but will be disposed within, the body of the denture.

In a fourth alternative process, illustrated in FIG. 30, the dentist fixes the alignment posts 156 directly to the copings 110. The alignments posts are suitably modified to mate with the copings 110 in a predetermined position, preferably coaxial with the copings, such that the surface extensions of the alignment posts can, as in the previous examples, be scanned and the location and orientation of the copings determined with some accuracy just as in the previous processes the surface of the fittings to which the alignment posts were attached was determined accurately using the surface extensions on the alignment posts.

In the discussion above, scans of surface extensions on the surface of alignment posts are used to provide a more accurate determination of the location of the objects to which they were attached. The position and orientation of these objects are determined by the position and orientation of the mounting surfaces of anchors embedded in the patient's maxilla or mandible. The scans therefore indicate, incorporate or encode the position and orientation of the anchors.

The alignment posts above are elongate members having spherical surface portions (e.g. the surface extensions) at various positions along their length. These are merely exemplary, however. FIGS. 31-36 illustrate alternative alignment posts 250, 252, 254 that provide scannable surface extensions that can be coupled to any of the structures indicate above to which the alignments posts of the foregoing FIGURES were attached to serve the same function: to provide scannable surface extensions that are in predetermined locations with respect to the mounting surfaces to which the base of the alignment posts are coupled. FIGS. 31-32 show an alignment post that is configured to be attached to any one of fittings 152C-152F. Referring to FIGS. 31 and 32, alignment post 250 is shown. It has three spherical surface extensions 256, 258, 260 that are in a predetermined position with respect to the base 262 of the alignment post 250. In this embodiment, the centers 264 define a plane that extends perpendicular to the longitudinal axis 266 of the alignment post 250. This axis 266 intersects the plane at a point equidistant to all of centers 264.

The point equidistant is a predetermined distance along axis 266 from base 262. Computer 186 is programmed with this parametric information and is configured to scan the surface extensions, determine the plane, determine the longitudinal axis and the position along the longitudinal axis where base 266 is located, as well as the location and orientation of the mounting surfaces of the structure to which the base is connected.

FIGS. 33-34 show another alignment post arrangement having a first spherical surface extension 268 lying on the longitudinal axis 272 of base 270. A second surface extension 274, shown here as a flat plane, is also disposed along and perpendicular to longitudinal axis 272 and a predetermined distance away from base 270. As in the previous examples, computer 186 is configured to scan the surface extensions, determine the center of spherical surface extension 268, determine the plane of surface extension 274, and determine the longitudinal axis 272 and the position along the axis where base 272 is located, as well as the location and orientation of the mounting surfaces of the structure on which the base 272 is connected.

FIGS. 35-36 show another alignment post arrangement having a first surface extension 280 forming a plane that is normal to the longitudinal axis 282 of base 284. A second surface extension 286, shown here as a flat plane, is disposed parallel to longitudinal axis 284 a first distance away from the axis. A third surface extension 288 shown here as a flat plane is also disposed parallel to longitudinal axis 284 the first distance away from the axis. A fourth surface extension 290 shown here as a flat plane is also disposed parallel to longitudinal axis 284 the first distance away from the axis. Each of the three surface extensions parallel to the longitudinal axis 284 are spaced equiangularly with respect to each other about the longitudinal axis to define an equilateral triangle in an end view (FIG. 36). As in the previous examples, computer 186 is configured to scan the surface extensions, determine the planes of the surface extensions center of spherical surface extension 268, determine the planes of the surface extensions determine the longitudinal axis 282 and the position along the axis where base 284 is located, as well as the location and orientation of the mounting surfaces of the structure on which the base 284 is connected.

We claim:

1. A method of generating a toolpath for manufacturing a dental framework to support a finished denture within a patient's mouth, the patient's mouth comprising a plurality of anchors embedded in the patient's mandible or maxilla, said framework being made from a stone cast with embedded analogs and a diagnostic wax-up, said diagnostic wax up replicating said finished denture, said stone cast being made from an impression having embedded copings, said impression being taken directly from said patient's mouth, wherein said framework further comprises a plurality of mating surfaces that are configured to engage the plurality of anchors, said framework further comprising a bridging structure that extends between and couples said plurality of mating surfaces together, the method comprising the steps of:

attaching alignment posts having surface extensions to each of said analogs;
digitally scanning said surface extensions including surfaces of said stone cast and said surfaces of said diagnostic wax up which represent surfaces of said mouth and said finished denture to generate a point cloud dataset;
deriving the relative positions and orientations of said mating surfaces from said point cloud dataset;

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deriving the positions and orientations of the bridging structures from said point cloud dataset;
generating a toolpath that is configured to generate said framework including said bridging structure and mating surfaces in their relative positions and orientations, permitting a computer controlled machine to manufacture said framework.

2. The method of claim 1, wherein the alignment posts are attached to surfaces of the analogs that correspond to the plurality of mating surfaces on the anchors.

3. The method of claim 1, wherein the step of digitally scanning said surface extensions further comprises a step of scanning said surface extensions with a laser scanner at a plurality of locations on each surface extension to produce a plurality of three dimensional datapoints, said point cloud dataset comprising said three dimensional datapoints.

4. The method of claim 1, wherein the step of deriving the relative positions and orientations further comprises a step of electronically fitting datapoints scanned from said surface extensions to a predetermined three dimensional geometry of the surface extensions stored in a computer memory.

5. The method of claim 1, further comprising a step of locating surfaces of said diagnostic wax-up with respect to surfaces of said stone cast, the method comprising the steps of:

scanning said diagnostic wax-up surface to create a first point cloud dataset;

scanning said stone cast surface to create a second point cloud dataset;

registering said first and said second point cloud datasets by aligning points in each dataset taken from the overlapping surface portions of the first point cloud data set and the second point cloud data set; and

using non-overlapping portions of the first point cloud data set and the second point cloud data set to digitally define the location of said dental appliance with respect to said stone cast.

6. A method of generating a toolpath for manufacturing a dental framework to support a finished denture within a patient's mouth, the patient's mouth comprising a plurality of anchors embedded in the patient's mandible or maxilla, said framework being made from a stone cast with embedded analogs, a diagnostic wax-up and a facial index, said diagnostic wax up replicating said finished denture, said facial index shaped from said diagnostic wax-up and said stone cast, said stone cast being made from an impression having embedded copings, said impression being taken directly from said patient's mouth, wherein said framework further comprises a plurality of mating surfaces that are configured to engage the

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plurality of anchors, said framework further comprising a bridging structure that extends between and couples said plurality of mating surfaces together, the method comprising the steps of:

attaching alignment posts having surface extensions to each of said analogs;

digitally scanning said surface extensions including surfaces of said stone cast and said surfaces of said facial index which represent surfaces of said mouth and said finished denture to generate a point cloud dataset;

deriving the relative positions and orientations of said mating surfaces from said point cloud dataset;

deriving the positions and orientations of the bridging structures from said point cloud dataset; and

generating a toolpath that is configured to generate said framework including said bridging structure and mating surfaces in their relative positions and orientations, permitting a computer controlled machine to manufacture said framework.

7. The method of claim 6, wherein the alignment posts are attached to surfaces of the analogs that correspond to the plurality of mating surfaces on the anchors.

8. The method of claim 6, wherein the step of digitally scanning said surface extensions further comprises a step of scanning the surface extensions with a laser scanner at a plurality of locations on each surface extension to produce a plurality of three dimensional datapoints, said point cloud dataset comprising said three dimensional datapoints.

9. The method of claim 6, wherein the step of deriving the relative positions and orientations further comprises a step of electronically fitting datapoints scanned from said surface extensions to a predetermined three dimensional geometry of said surface extensions stored in a computer memory.

10. The method of claim 6, further comprising a step of locating surfaces of said facial index with respect to surfaces of said stone cast, the method comprising the steps of:

scanning said facial index surface to create a first point cloud dataset;

scanning said stone cast surface to create a second point cloud dataset;

registering said first and said second point cloud datasets by aligning points in each dataset taken from the overlapping surface portions of the first point cloud data set and the second point cloud data set; and

using non-overlapping portions of the first point cloud data set and the second point cloud data set to digitally define the location of said facial index with respect to said stone cast.

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